

USE OF ALCOHOL IN AN
INTERNAL COMBUSTION
ENGINE

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THE
USE OF ALCOHOL
IN AN
INTERNAL COMBUSTION ENGINE

A COMPARATIVE SERIES OF TESTS

ON A BLACKSTONE OIL ENGINE

USING ALCOHOL AND COAL OIL

MCGILL UNIVERSITY

G.L.GUILLET.

1909

BLACKSTONE

4 H.P. OIL ENGINE

DIMENSIONS

Cylinder Diameter 5. ins

Stroke 10.875 ins

Clearance Volume 77.6 cu.ins

Piston Displacement 214.cu.ins.

Ratio of Compression 3.75

Theoretical Compression Pressure 91.6lbs/sq.in

Actual Compression :-

(1) Air Valve Open 50lbs/sq.in

(2) Air Valve Closed 45lbs/sq.in

Effective Brake Wheel Diameter 15 $\frac{5}{8}$ ins.

Single Cylinder Horizontal, Stationary
Otto, 4-Cycle.

FUELS.

"PRIME WHITE" CANADIAN COAL OIL.

Cost 17¢ per gal
Specific Gravity 80.2%
Calorific Power { Higher - 19,700 B.T.U./Lb.
Lower - 18,600 B.T.U./Lb.

WOOD ALCOHOL (METHYL)

Cost 90¢ per gal.
Specific Gravity 81.2%
Calorific Power { Higher - 9,400 B.T.U./Lb.
Lower - 8,700 B.T.U./Lb.

METHYLATED SPIRITS (ETHYL)

Cost \$1.10 per gal.
Specific Gravity 81.7%
Calorific Power { Higher - 10,500 B.T.U./Lb.
Lower - 9,900 B.T.U./Lb.

During the^{//}last few years the possibilities of alcohol as a fuel for internal combustion motors have been brought before the manufacturers and owners of motors on many occasions. Gasoline, the fuel in common use at the present time, while now a fairly cheap and efficient fuel, may and probably will in the near future advance considerably in price. The rapid increase in its consumption lately and the fact that, being a by-product of coal oil, its output is more or less limited, leads us to believe that very soon the market value will rise, and in consequence we shall be obliged to look for some other source of power which can be applied in its stead to large and small internal combustion engines.

Among the other fuels on the market, ~~alcohol~~ alcohol looks as promising as any. Its cost of production plus a reasonable profit should not exceed that of coal oil or gasoline and the supply is practically unlimited - it can be produced in any quantity to meet the demand since raw material is plentiful. Then again the cost of production is quite liable to decrease as its use becomes more general.

Gasoline as a fuel for automobiles, motor boats, etc. has several objectionable features among which are the odor of the exhaust and the liability to explosion.

<u>Temperature</u> °F.	<u>Vapor Pressure of Saturation in Millimetres of Mercury.</u>			
	<u>Pure Ethyl Alcohol</u>	<u>Pure Methyl Alcohol</u>	<u>Water</u>	<u>Gasoline</u>
50.	24.	54.	9.	133.
68.	44.	94.	17.	179.
86.	78.	159.	32.	251.
104.	134.	259.	55.	360.
122.	220.	409.	92.	493.
140.	350.	624.	149.	648.

Both these ~~objections~~ would be partially overcome by the use of alcohol, - the exhaust has only a mild odor and the possibility of explosion is much lessened.

Comparing the average heats of combustion of alcohol, gasoline and coal oil, the two latter being practically the same, we find a considerable difference. Alcohol ($C_2 H_5 O H$) that is the methyl form, has a heat of combustion of 10,000 B.T.U. per lb. or 5,500 Calories per kilogram. For gasoline or coal oil, this value is found to be about 19,000 B.T.U. per lb. or 10,500 Calories per kilogram. Thus we see that the more commonly used fuels have about double the calorific power of alcohol. This does not look very promising in the light of high power for small fuel consumption. When, however, we consider the power which can be developed in a given size of cylinder, the matter is placed on a more equal footing with a slight advantage in favour of alcohol.

Supposing our piston displacement to be 10 litres, we fill it with air under standard conditions and then burn in it the maximum quantity of the two kinds of fuel, alcohol and gasoline. For complete combustion, 1 Kgm. Alcohol requires 6.616 cu. metres of air, 1 Kgm Gasoline requires 12.83 cu. metres of air. By the ten litres of air, then, there would be burned $\frac{10}{6.616} = 1.52$ gms. alcohol.

and $\frac{10}{12.83} = .779$ gms. gasoline.

Or the heat generated would be

For Alcohol $1.52 \times \frac{5500}{1000} = 8.36$ calories.

For Gasoline $.799 \times \frac{10,500}{1,000} = 8.18$ calories.

Hence a larger quantity of heat would be liberated when alcohol was used, and we would therefore expect, provided that we could use the alcohol with the same efficiency as gasoline, that it would give a slightly higher power in the same engine. Consequently where high power in a minimum space is essential, as in the case of ~~motors~~^{power} for ~~power~~^{motor} boats, automobiles, motor cycles and aerial work, alcohol ought to be suitable from this point of view.

Then there is the question of vaporization. Can alcohol be carbureted in as efficient a manner as gasoline or coal oil, and if so, can it be done by the carburetors at present in use without any radical alteration, except that provided for in the way of needle or air valves? Examination of the vapor pressures of the fuels under consideration as shown in the appended table gives us some light on what may be expected in this regard. Gasoline is quite a variable quantity and hence the figures shown for it may only be taken as approximately correct. This table shows that gasoline is much more easily vaporized than either kind of alcohol, and

also that there is a considerable difference between Methyl or Wood Alcohol ($C_2 H_5 O H$) and the Ethyl Alcohol or Spirit of Wine ($C H_3 O H$). It might be surmised that Methyl Alcohol would give better results on an ordinary vaporizer, and, as we shall see later on, this was found to be the case.

The main object of the test was to find out the conditions necessary for the use of alcohol and to make a comparison between the operation with this fuel and that obtained when the fuel for which the engine was built was used. It was desired primarily to find out whether alcohol could be used on the engine as delivered by the makers and if not what alterations would be necessary.

Trials were run on both fuels at various loads, -, no load, $\frac{1}{4}$ load, $\frac{1}{2}$ load, $\frac{3}{4}$ load and full load. At each load at least three trials were run, using different settings of the valves, the object being both to find out the best valve setting and to get an idea of the loss in efficiency and increase in cost of operation due to the use of other settings than the best.

FUELS.

Prime White Canadian Oil was used during these tests, costing 17¢ per Imperial Gallon. Tests were made to determine its calorific value, using a Junker Calorimeter under which a measured quantity was burnt. The amount of cooling water used, its rise in temperature and the amount of condensed water were recorded. From these observations the higher and lower calorific values could be calculated. The two tests made gave average results as follows:-

Higher Calorific Value 19,700 B.T.U. per pound.

Lower Calorific Value 18,600 B.T.U. per pound.

As, in the engine, the water of condensation goes off as a vapor, the latter of these two values was used in all calculations. The specific gravity was ~~also~~ found by accurately weighing 200 cubic centimeters of the oil and gave as a result .802.

Two varieties of alcohol were tested, Wood Alcohol or Denatured Spirit and Methylated Spirit. The Wood Alcohol which in its pure state has the chemical formula C_2H_5OH , is a Methyl alcohol and gave results in the calorimeter tests as follows:-

Higher Calorific Value 9,400 B.T.U. per pound.

Lower Calorific Value 8,700 B.T.U. per pound.

Two tests were made, about 50 gms. being burnt under the

calorimeter in each case and the results were found to agree quite closely, being less than 100 B.T.U. different in the two determinations. The specific gravity was found to be .812, which would indicate that the percentage by weight of pure alcohol in the mixture is 93.9, assuming that the other ingredient is water. This alcohol was purchased as the standard commercial article, and cost 90¢ per Imperial Gallon.

The Methylated Spirits had a specific gravity of 81.7, indicating 92.07% of pure alcohol with the assumption, as before, that water makes up the balance of the mixture. Methylated Spirit consists of Ethyl alcohol with a small percentage - usually about 10%, of Wood or Methyl Alcohol added. Ethyl alcohol has the chemical formula C_2H_5OH and is more frequently known as Spirit of Wine. The sample with which we have to deal gave in the calorimeter tests these figures:-

Higher Calorific Value 10,500 B.T.U. per pound.

Lower Calorific Value 9,900 B.T.U. per pound.

Two tests were made as in the other cases, the results checking very closely. The price per gallon was \$1.10.

It will be noted that the purchase price of both varieties of alcohol are extremely high, being far above the cost of production plus a reasonable profit. This is due to

APPARATUS USED.

The engine on which these tests were made was a Blackstone Oil Engine constructed to run on ordinary coal oil and also supposed to be capable of operating efficiently on alcohol or gasoline.

P.C. It is a single cylindered, horizontal, four-cycle engine of the Otto type of action, rated at four horse power and running at about 260 R.P.M. Its cylinder diameter is 5 inches; stroke 10.875 inches. This gives a mean piston velocity of 450 feet per minute. The piston displacement figures out at 214 cubic inches, the clearance volume is 77.6 cubic inches, giving us a total ratio of compression of 3.75. Supposing that the cylinder volume is filled with air at atmospheric pressure at the beginning of compression, and it is compressed adiabatically using $\gamma = 1.38$, our theoretical pressure at the end of compression would be 91.6 lbs. per sq. inch. The actual pressure obtained in the engine as measured on the indication cards is approximately 50 pounds per sq. in. This reduction is due to several causes, - suction through the valves reduces the initial pressure; the compression is not adiabatic, as heat will be radiated to the cylinder walls during the latter part of the compression, and also a slight leakage probably exists.

The brake wheel has an effective diameter, - measured from centre to centre of the rope, of $15\frac{3}{4}$ ins. The cylinder has a water jacket, with inlet below and outlet above, for cooling purposes and in the practical operation of the engine, this jacket would be connected with a cylindrical tank standing vertically, so that "gravity" action due to the difference in weight of the cool and heated water would produce and keep up a circulation. During these tests, however, the water was merely run through the jacket to weighing tanks where the quantity supplied could be reported.

The engine being of the four-cycle type with one explosion for every two revolutions of the fly wheel, the valves are of necessity of such a type as to produce any required motion once in two revolutions. This is effected by operating the valves in a manner quite generally used in the various forms of internal combustion engines. Cams of the proper form are placed on a shaft at right angles to the driving shaft of the engine, the two shafts being connected by a screw gear with speed ratio of 2 to 1. This cam shaft has on it four cams for the operation of the same number of valves, the latter being returned to closed position by springs. It also carries a governor whose action will be noted later.

a heavy Government tax, and prevents alcohol from being placed on a fair basis of dollars and cents when compared with oil and gasoline fuels, which are not similarly handicapped. Denatured Alcohol may be purchased for about one-third of the above price, in the United States where the Government tax does not exist.

The various valves are:- the exhaust valve; the gas valve which admits the fuel-charged air to the vaporizer; the air valve which supplies an excess of air to the cylinder necessary for a proper explosive mixture; the ignition valve by which the time of firing the charge is regulated. The exhaust valve is placed on the lower side of the cylinder, the air valve on top, while the ignition valve controls communication between the cylinder and the vaporizer in which the hot "ignition tube" is placed.

The engine is governed by the "hit and miss" method, that is it does not vary the mixture to suit the load as is the case in some gasoline engines, but cuts out an explosion when the speed becomes too great. It effects this by not allowing the gas valves, which bring in the explosive portion of the charge, to open.

This governor is the centrifugal type, being enclosed in a cylindrical shell carried on the valve operating shaft. When in action the governor releases a ratchet on the cam which operates the valve, ~~opening the mechanism~~ allowing the latter to swing so that the projection which would cause the lift of the roller under normal conditions is swung towards the axis of rotation, and consequently no motion is transmitted to the valve.

It will be noted that by this method of governing all other valves are in operation during a miss as well as

during an explosion cycle. In other words what happens during the miss cycle is that a charge of pure air is drawn in from the auxiliary air valve, compressed, expanded and driven out the exhaust. Hence we get a cooling and scavenging action which has a noticeable effect on the next explosion as will be seen from the indicator cards.

This oil engine has a vaporizer^{and} igniter in a separate casting bolted to the cylinder head. This vaporizer communicates with the cylinder by means of the ignition valve as noted above, the latter being capable at the proper time of closing ~~off~~ communication between them. A high temperature is maintained in the vaporizer by the heat given to it by the explosive mixture. To start the engine on coal oil^{it} is necessary to heat the vaporizer considerably, provision being made for so doing by the removal of a slide in the outer casing. The flame of a lamp is allowed to circulate between this casing and the vaporizer proper until the latter attains the necessary temperature.

The next point to be considered is the method of supplying the fuel to the vaporizer. The fuel supply is obtained from the receptacle containing it (during the test a glass graduate calibrated in centimeters was used) - by a pump worked by a cam on the valve operating shaft which forces the oil up a small pipe to a fuel chamber. This fuel chamber has a partition across its centre, one pocket

being connected to the supply from the pump and the other by an overflow pipe to the fuel vessel.

The pump supplies an excess over what is used by the engine, the surplus being returned by the overflow pipe, hence we have one pocket of the chamber always filled to the partition top. A small duct leads from this pocket to the fuel nozzle - the latter as supplied by the makers having a diameter of .06 inches. This nozzle is situated in the suction pipe, which leads to the vaporizer. The top of the nozzle is about .25 inches above the level of the fuel in the supply chamber, consequently the suction due to the piston receding must overcome this difference in level in order to obtain a supply of fuel. Between the suction pipe and the vaporizer is located the gas valve, which when open allows a charge to be sucked in past the fuel nozzle.

As provided by the makers, there is no regulation for the fuel nozzle in the way of a needle valve or similar contrivance to partially close it. However when using coal oil, sufficient regulation may be obtained by manipulating the gas valve mechanism. A bell crank lever, one end being a "knocker" acting on the valve spindle, the other carrying a roller which bears on the operating cam, moves the valve. The knocker is in the form of a set screw which may be rotated, hence causing any desired lift of the gas valve.

At the beginning of the trials the set screw was marked in a certain position when its head was a distance of 1.082" from the back of the supporting arm. This was used as zero position and other positions were referred to this one in accordance with the number of turns the head was rotated. + turns indicate a movement which would cause a larger valve lift, and hence a stronger explosive mixture, - turns indicating the opposite effect. The pitch of the thread on the knocker is 16 per inch, so that each turn corresponds to a change in valve lift of $1/16$ ".

It was found when alcohol was used on the engine that the above regulation using the gas valve was insufficient, - that even using the maximum opening obtainable by this means, enough fuel to drive the engine could not be obtained, due to the small size of the fuel nozzle. The hole in the latter was therefore enlarged to $1/8$ ", and a needle valve giving any size of opening from 0 to $1/8$ " was put on. This gave the needed control of the fuel supply, independent of the gas valve. The

needle valve was used for the alcohol tests only, the .06" Diam. nozzle provided by the makers of the engine being used during all ^{Cool oil} tests. Following the course of the explosive charge when obtained from the fuel nozzle, it traverses a short pipe, passes the gas valve into the vaporizer where the small particles of liquid, which have been swept along by

the suction, due to the recession of the piston, strike the hot surfaces of metal and are transformed into the gaseous state necessary for an explosive mixture. It then passes the ignition valve into the cylinder, there meeting and mixing with a quantity of additional warm air, which has been drawn in through the air valve. This air comes in through the frame of the engine to a chamber at the crank end of the cylinder where its temperature is raised before it is used. The supply pipe has a butterfly valve capable of being rotated 90°, the object of this being to provide a means of cutting off the auxiliary air supply when starting the engine. When closed, all the charge is drawn in past the fuel nozzle and gas valve, thereby increasing the chance of obtaining a rich enough mixture to put the engine into commission.

The ignition is of the hot tube variety. It consists of a small chamber in the vaporizer, containing a piece of 1/8" wrought iron plate rolled up into a loose cylinder, which retains the heat imparted to it by one explosion until a fresh charge comes in contact with it. No lamp or outside source of heat is required after the engine is once started. This form of ignition was found to be satisfactory when coal oil was used, but during the alcohol tests, another method was necessary as will be explained later.

The engine was equipped with a water cooled brake wheel, having an effective braking diameter of 15 5/8". The brake was of the usual type, of rope, with an iron stand mounted on scales capable of recording a weight of two hundred pounds. The direction of motion of the brake wheel is such as to increase the weight on the scales when running under load. The pull due to the rotation is measured by the scale reading when running minus the initial weight of the stand, etc.

Other apparatus used consisted of a Crosby Gas Engine Indicator, Counters for obtaining the revolutions and Ignitions, the latter being attached to the gas valve; weighing tanks for cooling water, and a glass graduate for the measurement of the fuel supply calibrated in cubic centimeters.

METHOD OF CONDUCTING TESTS.

The readings were in general taken every two minutes during the tests and consisted of the following:-

- (1) Fuel used.
- (2) Explosions.
- (3) Revolutions.
- (4) Indicator Cards.
- (5) Cooling Water weight and temperatures.
- (6) General observations on the action of the engine.

The indicator cards obtained were of two types, the kind taken in the usual manner and those obtained by rotating the Indicator ^{barrel} ~~driver~~ uniformly by hand instead of giving it a motion by reducing gear proportion to the piston displacement. Horizontal distances on this form of card possess no particular significance, but the vertical heights of the lines give us a record of the maximum pressures obtained and an idea of the regularity or otherwise of the explosions. They show whether the Governor is acting properly, and whether the mixture used is giving good results.

The indicator was attached as closely to the cylinder as possible, being screwed into a right angled elbow, the length of orifice from indicator cock to inside of cylinder would be about 6" with one right angled

turn. A spring giving a lift of one inch for two hundred pounds per square inch was used during all trials.

A minimum time of ten minutes per trial was used, it being considered that the fuel measurements could be taken as accurately as the brake load for this time. Fuel ^{cubic} could be recorded to within 2 centimeters, and this gave a possible error of about 1% on a ten minute run, which was probably fully as accurate as the other determinations.

RESULTS OF TESTS.

The operation of the engine was very satisfactory when "Prime White" Canadian oil was used as fuel. There was little difficulty in starting, a lamp using coal oil as fuel, built on the same principle as the ordinary gasoline lamp with air pump and vaporizer tube, was used to heat the vaporizer on the engine. This took an average time of five to ten minutes, and then by a couple of revolutions of the fly wheel with the exhaust cam on half-compression and the butterfly valve on the air pipe closed, the engine could be started. Some difficulty was found with the valves - those controlling the gas supply and the ignition having a decided tendency to become clogged after the engine was run for a few hours. These valves seem to require cleaning quite frequently when coal oil is used as fuel, whereas during the alcohol test no trouble from this source was experienced. The coal oil tests lasted twenty minutes, all the conditions of operation being ~~kept~~ as constant as possible during that time. It was found that at 265 R.P.M. the highest power which the engine could develop, was 3.49 H.P. as seen by the results of Test L. Maximum load was taken as being reached when the misses were one in ten. A small^{-er} percentage of misses than this gave a considerable drop in speed. In order to obtain even this H.P., it was necessary to use a very rich mixture. During all the coal oil tests the .06" Diam.

fuel nozzle was used and the regulation in the strength of mixture obtained by rotating the "knocker" for the gas valve. The air valve was kept open except at starting. Three trials were run at each load with different valve settings.

Specimen cards of this series are shown in plates A and B.

Taken as a whole, the series shows that as might be expected, the engine is slightly more economical at higher loads, the difference in economy between $\frac{1}{4}$ and full load being about 25%, which may be considered as fairly good. The average fuel consumption at all loads with best valve setting for each figures out at 1.00 pound per horse power hour.

For each load, there seems to be a valve setting, which will give the highest efficiency, and this best setting is different for different loads. For instance trials F.G.H. are at quarter load. F gives best results 1.18 lbs. per B.H.P. with gas valve at $-1/6$ from normal. At half load (trials B,C.D.E) the best results were obtained with gas valve at $-1/6$, .97 lbs per B.H.P. At three-quarter load (trials I.J.K.), J with valve at $+2/6$ gives .918 per B.H.P. hour. At full load (trials L.M.) there is an apparent increase in fuel consumption. The explanation is

that a stronger mixture had of necessity to be used in order to develop the full power, and this strong mixture proved to be not as economical as a weaker one. The explosions were quite loud and sharp during trials K, L M, and there is an increase of about ten pounds in the Mean Effective Pressure over the average during the other trials. As shown on Plate A, a maximum pressure of 270 lbs. is recorded for these trials as compared with 200 lbs. for the others. It will be noted, however that these maximum pressures as recorded are probably much higher than actually exist on account of the inertia of the moving parts of the indicator. However, the results are interesting from a comparative point of view. The wavy appearance of the expansion line near its beginning as seen in many of the indicator cards is also probably due to the indicator spring. Using a spring of different size, had no apparent effect in reducing this irregularity; it still had a vibration due to synchronism with the explosion wave.

Due to an irregularity of the explosions which cannot be eliminated and a consequent variation of the cards obtained in the same trial, the calculated I.H.P. is a quantity which is only approximate with wide margins. Hence any further deduction bases on it are not nearly as reliable as those figured from the B.H.P. values. The cost, ~~at~~ about 2¢ per B.H.P. hour, will compare quite favourably with

many gasoline engines.

Considerable difficulty was experienced in getting this engine to operate satisfactorily on alcohol. It was first tried without any alteration of the fuel supply or form of ignition, the object being to determine whether ^{with} the structure and adjustments provided the engine could be made to run properly.

The first point brought out was that the engine as it stood could not be started on alcohol, though the lamp was used to heat the vaporizer. Having first been heated up and started on other fuel, alcohol was substituted. The gas and air valve settings were varied, and the effect noted. It was found that if a considerable load was put on the engines before changing the fuel, it would run on alcohol but not at all well - explosions obtained being very weak and uncertain; all admissions did not explode and the engine slowed down on each occasion to less than half speed. The best results, and these very poor, were obtained when the gas valve was set at + 2 turns and the butterfly valve in the air pipe half or entirely closed.

Plate C shows the effect of the different adjustments. As soon as the oil fuel was replaced by alcohol without any valve change, the explosions weakened quite considerably - probably due to the engine not getting

a sufficiently strong mixture (see Card a) The gas valve was then moved to + 2 and the butterfly valve in air pipe set in mid position, hence increasing both the gas valve opening and the suction in the fuel pipe; (b) shows the results of this change, - a higher mean effective pressure with better ignition. The explosions are strong, but there is a wide variation in the cards. ^{Not} Every fuel admission ~~did~~ [^] ~~not~~ exploded. (c) was taken with a still stronger mixture.

The effect of opening and closing the butterfly valve in air pipe are shown on card (d) indicating that a stronger mixture was needed. Card (e) shows the variation in the explosions obtained.

These results, though in themselves not of much value, gave an idea in what direction we might look for an improvement. The main troubles seemed to be

- (1) Insufficient fuel supply.
- (2) Faulty ignition or Vaporization.

To endeavour to remedy the first of these, a needle valve and large $1\frac{1}{8}$ " nozzle was substituted for the small nozzle without regulation, which came with the engine. The zero position of the needle valve during the following tests was taken as the average setting for coal oil, the valve being then open $1\frac{1}{2}$ turns, and in the tabulated results +

angles indicate additional opening from the zero position and -angles a lesser opening.

The addition of this valve to the equipment of the engine did not produce the desired results. The engine could not be started on alcohol, neither would it run at full speed. The cards obtained showed the same irregularity as before, slow burning in many cases instead of an explosion. The use of the lamp under the vaporizer did not seem to afford any improvement in the vaporization or ignition. The problem now narrowed itself down to a question of which of these two things was at fault, as it was now known that plenty of fuel was being supplied. Alcohol being more easily vaporized than coal oil, the conclusion arrived at was that the charge did not ignite properly from the hot tube.

Acting on this deduction, an attempt was made to equip the engine with a satisfactory electric sparker. The type used consisted of a spark coil with trembler, a primary circuit with a timer and batteries in series and the secondary connected to a spark plug of the usual type. The contact timer was formed of two copper springs placed one on the frame of the engine and the other on the lever which actuated the timing valve for the hot tube ignition. These were arranged so that they came together at the proper instant, and produced a series of sparks at

the plug in the secondary circuit. A rubber insulator on one of the contacts insured that there was no spark produced as the lever made its return motion at the opposite end of the stroke of the engine.

The spark plug was at first placed in the end of the vaporizer, remote from the cylinder, ~~it~~ occupying the exact point previously occupied by the hot tube igniter.

Under these conditions then, the engine was warmed up on other fuel and tried again on alcohol. For a short time it seemed that the experiment was going to be a success, good cards being obtained and a high speed being maintained. But when running a few minutes, it began to slow down as before, and ignitions again became irregular. Adjustments of the various valves had little effect. The cards show ignition to be taking place quite late, sometimes after one-eighth or one-quarter of the stroke had been completed. Advancing the spark did not remedy this. At intervals the engine would speed up, but the increased rate of revolution did not last.

It seemed possible that the spark plug might not be in a favourable position, being in the back of the vaporizer, and out of the current of gas. The entering mixture comes through a valve in the side of the vaporizer, about five inches from the point at which the spark was placed, and flowed forward and away from the spark.

Consequently it was thought that the spark lost its effect by being buried in burnt out gas. This theory was strengthened by the fact that explosions were obtained after several misses when the scavenging action would naturally have swept away the blanket surrounding the spark.

On this hypothesis, the position of the spark plug was changed, the ignition or timing valve between cylinder and vaporizer being removed, and the spark plug substituted. Here it is in the direct current of the gases entering the cylinder. This proved to be the last change which it was necessary to make in order to use alcohol. The only thing now required being the proper adjustment of valves, and time of ignition.

It was found that for a satisfactory indicator card, ignition at each fuel admission, and other indications of efficient operation, the air valve should be kept almost or wholly closed, that the gas valve should be regulated to give a larger lift (+ 2 turns being the setting used in all alcohol trials) and that the needle valve should be opened just a little more than for coal oil, the average setting being about + 45°.

Keeping the air valve closed reduces the compression pressure from fifty to barely forty-five pounds. It also produces a still lower compression line on a "miss" cycle, when the gas valve does not open and the charge must of

necessity leak in past the loose-fitting butterfly valve in the air pipe. This line shows up clearly on many of the cards in Plate D. In the coal oil tests the butterfly valve was always open, hence for these trials the compression was over five pounds higher, and therefore the possible efficiency slightly higher.

Tests were made on Wood Alcohol at $\frac{1}{4}$, $\frac{1}{2}$ and $\frac{3}{4}$ load. It was found to be impossible to carry more than 3.2 H.P. with alcohol as compared with 3.5 for coal oil. The reason for this was that with alcohol when the misses became less than about one in five, the engine would miss fire on a fuel admission and slow down. The mean effective pressures obtained were higher than for coal oil, averaging about 70 lbs. per square inch, whereas the oil gives an average about 15 lbs. less.

The thermal efficiency based on the I.H.P. give average values for alcohol of about 19% as compared with practically the same values for coal oil. The maximum efficiency given by the formula

$$E = 1 - \left(\frac{I}{R}\right)^{\alpha-1}$$

R being 3.75 and α being taken as 1.38 gives a result of .396.

Consequently our efficiency ratio is about 50%. The actual work obtained is much less than that indicated, in other words, the apparent mechanical efficiency is low, but its

value is no doubt decreased by the lowering of the value of the B.H.P. by weak explosions which sometimes occur, but are not always recorded on the indicator cards. ✓ During In the ~~fabulated results~~ The Thermal Efficiencies shown are based on the alcohol tests, there were also at times, though not the I.H.P. frequently, fuel admissions not followed by an explosion. These were registered on the counter attached to the gas valve and give an apparent I.H.P. higher than that actually developed. It was noted also that the governor sometimes had a partial action, that is it caused the valve to open slightly, and in this case a weak explosion took place. No explosions were noted during a miss cycle using either kind of fuel. Consequently, if the cylinder does retain fuel in liquid form and act as an auxiliary vaporizer during miss cycles as has sometimes been claimed, the action did not take place in a sufficient degree to produce a mixture which would ignite.

The curves appended show the best fuel consumptions obtained with both alcohol and coal oil. These indicate that the engine uses over double the weight of alcohol that it does of coal oil for the same B.H.P. The thermal values are in the ratio of 8,700 to 18,600 or 1 to 2.14. Hence for equal ^{overall} thermal efficiencies, we would have fuel consumptions in the same ratio. At $\frac{3}{4}$ load this is nearly the case, the relative values with best valve setting in each

case being .92 to 2.06 or 1 to 2.24. At half load this ratio is 1: 2.53 and at $\frac{1}{4}$ load 1: 3.05. The alcohol curve rises very rapidly at small loads, the increase in the best consumption recorded from three-fourths to one-fourth load being about 75% whereas the coal oil curve is quite flat and shows an increase of only about 25%. The explanation of this probably lies in the fact that the vaporizer is kept hotter at heavy loads, and that therefore we get more complete vaporization of the alcohol, and less waste due to unvaporized fuel being carried out the exhaust. At all loads the vaporizer works equally well with coal oil. The 25% increase there is due to the drop in the mechanical efficiency at light load. The oil consumption per I.H.P. - hour remains approximately constant for all loads.

Curves showing the results obtained with different needle valves setting for the alcohol valves were plotted. These indicate in a general way that the best fuel consumption is obtained when a rather weak mixture is used. The heavier the load the stronger the best mixture. The curve for $\frac{1}{4}$ load does not seem to have attained its lowest point, as it is still sloping down at - 45° needle valve setting. It was found, however, that a weaker mixture caused misfires and consequent slow downs.

The increase in full consumption due to an incorrect setting with alcohol is very considerable, and will

easily amount to 25% without any apparent difference in the indicator cards or action of the engine. The only means of detection would be a brake test.

This is true to a lesser extent with coal oil, the loss there being only about 15% before the engine begins to give indications of an incorrect fuel supply.

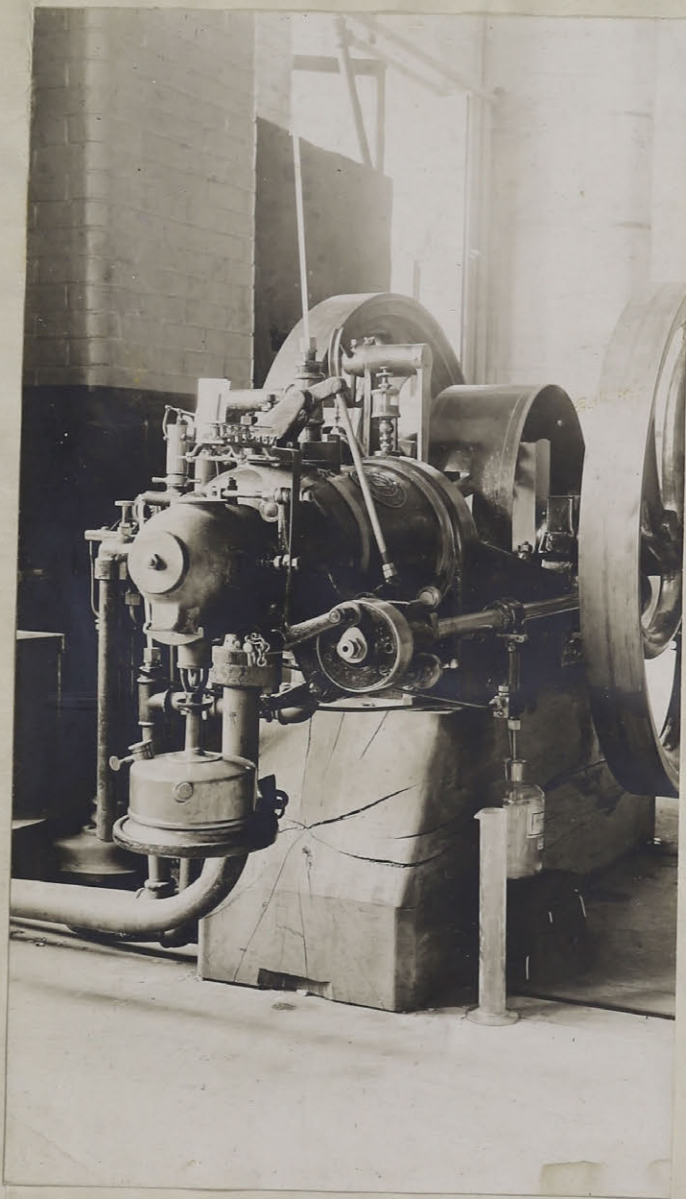
A few tests were made using methylated Spirits as fuel. These tests were not as satisfactory as the Wood Alcohol tests on account of miss-fires. This was especially apparent during trial A. It could not be expected that this fuel would operate as well as Wood Alcohol, Methylated spirits being chiefly an Ethyl alcohol with therefore a lower vapour pressure, and less tendency to vaporize easily. It was found impossible to get a satisfactory test of the methylated spirits at the lower loads on account of these miss-fires, and only one could be obtained at half load. Various times of ignition and valve settings were tried without result. The conclusion arrived at was that except at high loads (and even then its action is doubtful -) the engine would not run properly on methylated spirits.

This form of alcohol costs 20¢ more per gallon than Wood Alcohol, the trials made show the fuel consumption to be no less than when using the other variety, consequently it looks much less promising as a fuel than the Denatured Spirit.

There is, little to be said in regard to the comparative cost of oil and alcohol fuel, the curves show ~~up~~ the deficiencies of alcohol in this respect very clearly. The ratio of expense of operation is about 13:1. As previously noted, however, this condition of affairs is not due so much to relative amounts used as to the high cost of the alcohol. In countries where no Government tax exists on alcohol, its price is about two-thirds lower, costing about thirty instead of ninety cents per gallon. Coal oil is very cheap by comparison.

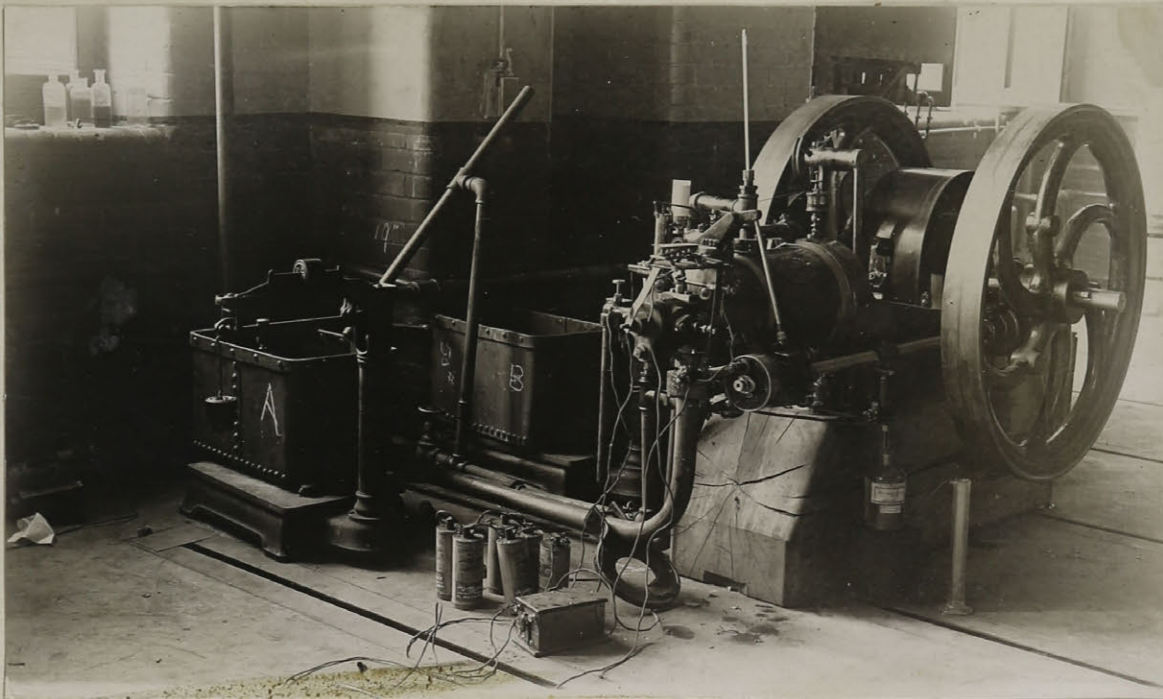
Other points noted were that it took less heating by means of the lamp to start the engine on alcohol than on coal oil, and if things were just right, a start could be made on the spirit without any preliminary heating; the explosive shocks were less violent with alcohol, although the mean effective pressures were higher, combustion taking place more as a burning action than as an explosive wave.

George L. Guillet

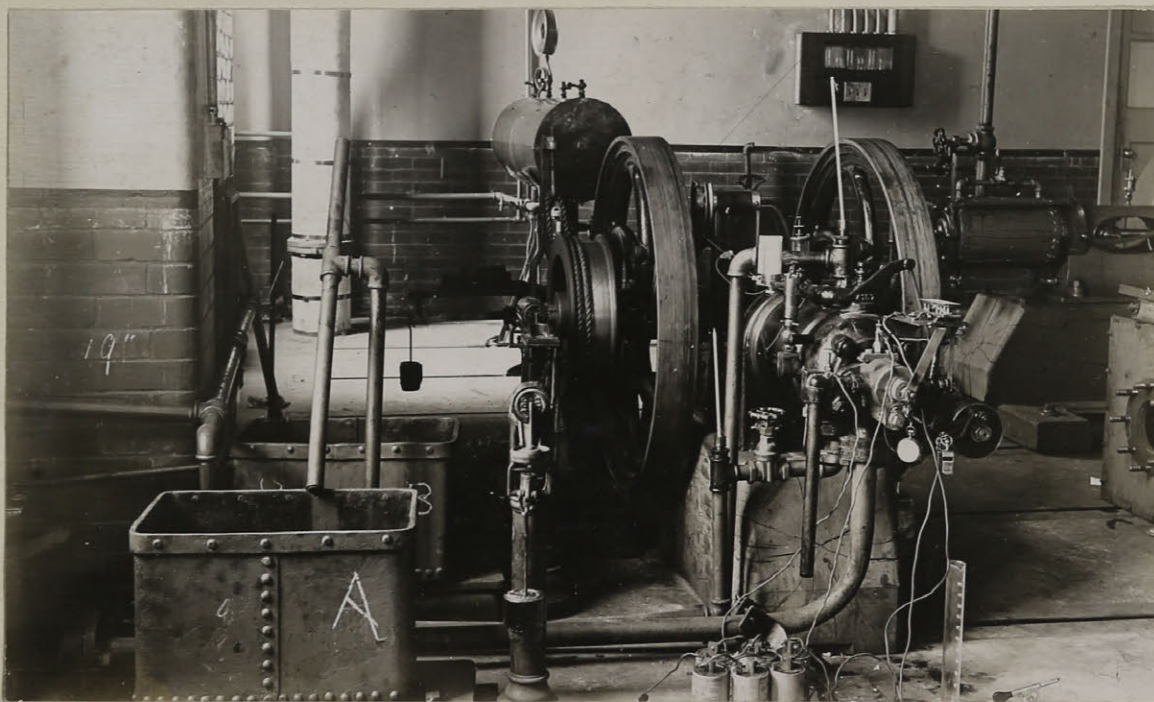


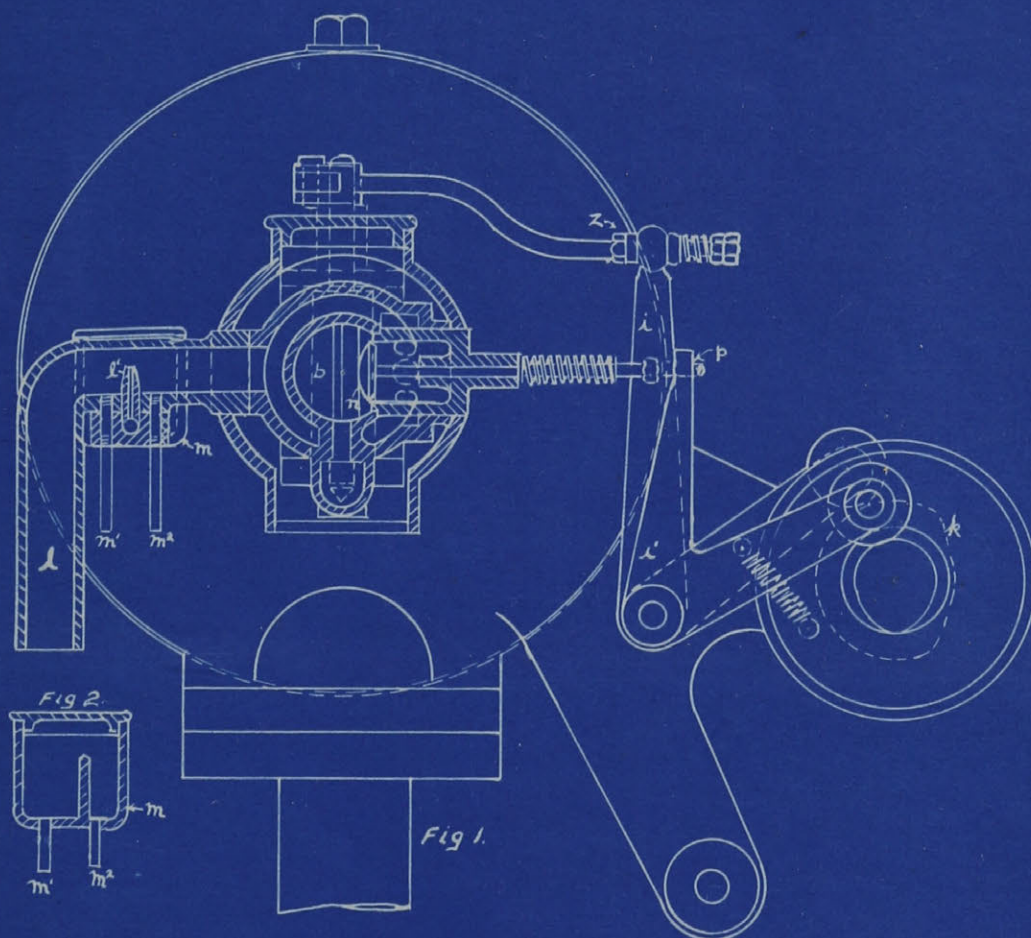
The Blackstone Oil Engine
and equipment used during the
trials with coal oil as fuel.

23/4



Views of the Blackstone Oil Engine
showing the equipment used during
the alcohol tests.

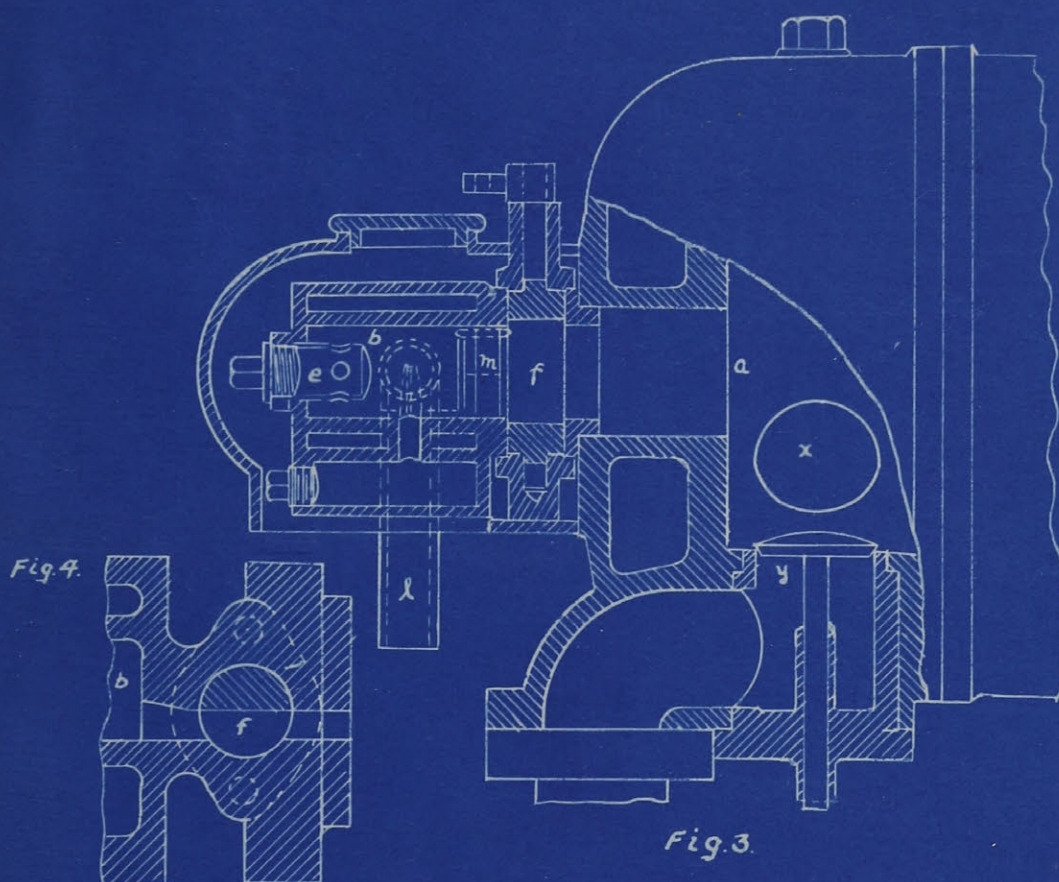




CROSS SECTION
THROUGH
VAPOUR VALVE AND INSPIRATOR

LONGITUDINAL SECTION

THROUGH CENTRE OF VAPOURISER

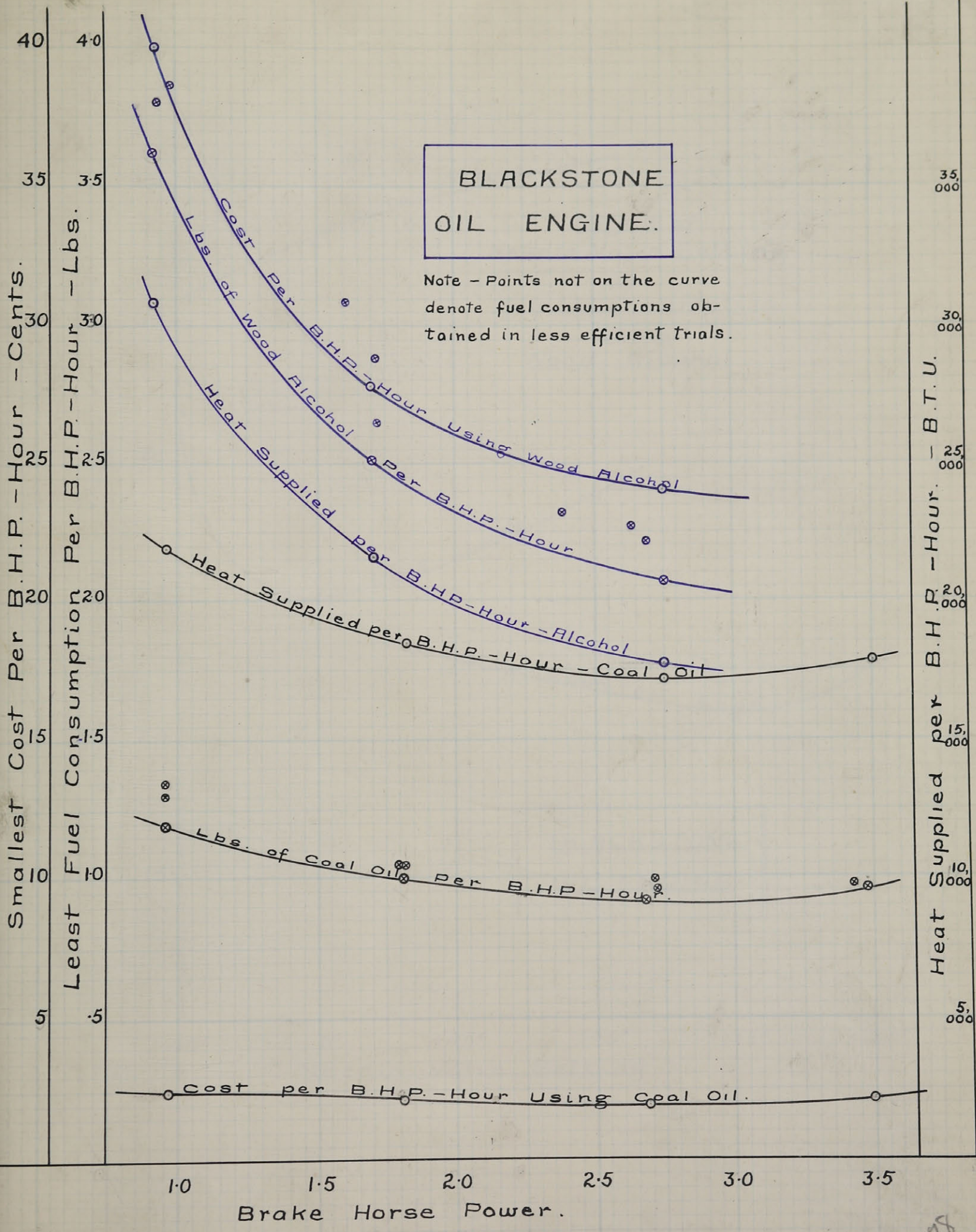


SECTION SHOWING
FORM OF IGNITION VALVE

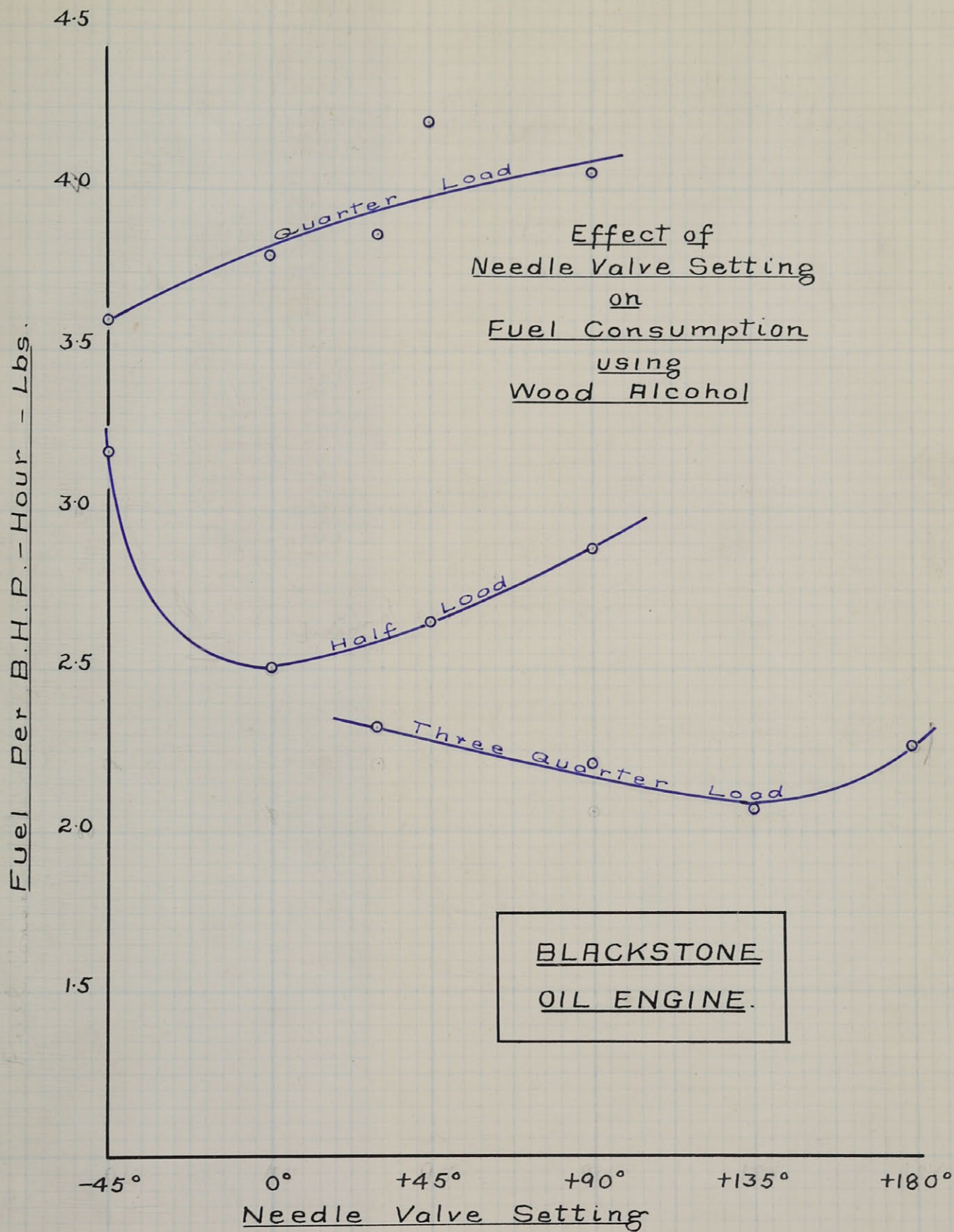
33/4 Slide

BLACKSTONE OIL ENGINE.

Note - Points not on the curve denote fuel consumptions obtained in less efficient trials.



10878

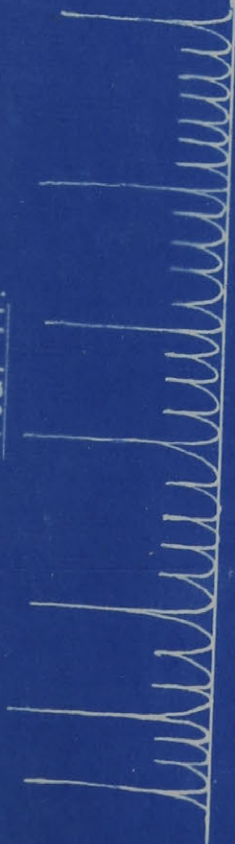


USING OIL FUEL

Plate A.

SCALE 200 LBS. PER INCH.

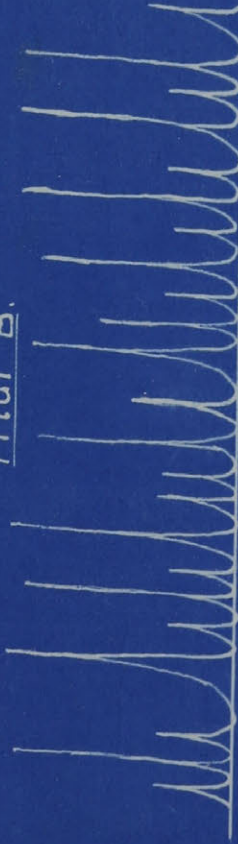
Trial A.



Av. Max.
Press.
170 lbs.
Fuel Cons.
—

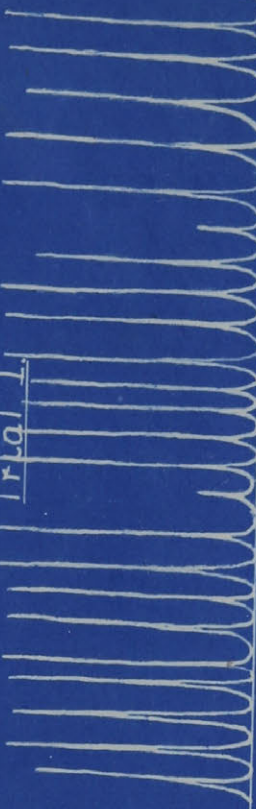
Av. Max.
Press.
210 lbs.
Fuel Cons.
130 lbs

Trial B.



Av. Max.
Press.
179 lbs.
Fuel Cons.
1.05 Lbs

Trial I.



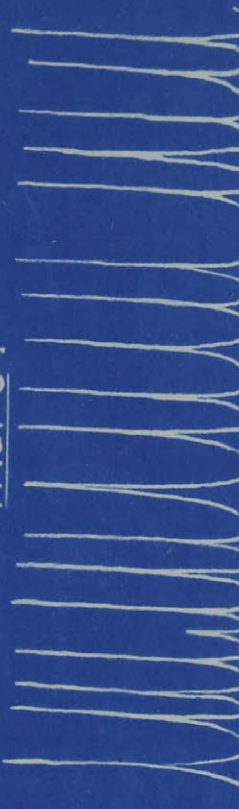
Av. Max.
Press.
230 lbs.
Fuel Cons.
924 lbs.

Trial C.



Av. Max.
Press.
195 lbs.
Fuel Cons.
97 Lbs

Trial J.



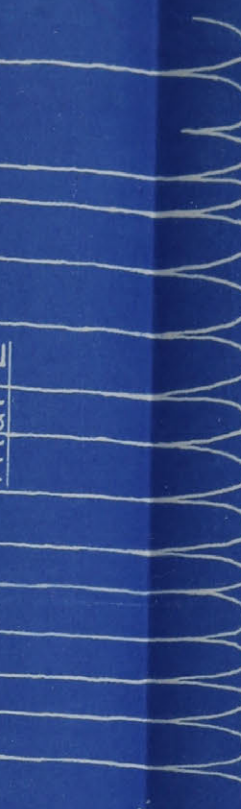
Av. Max.
Press.
208 lbs.
Fuel Cons.
938 lbs.

Trial E.



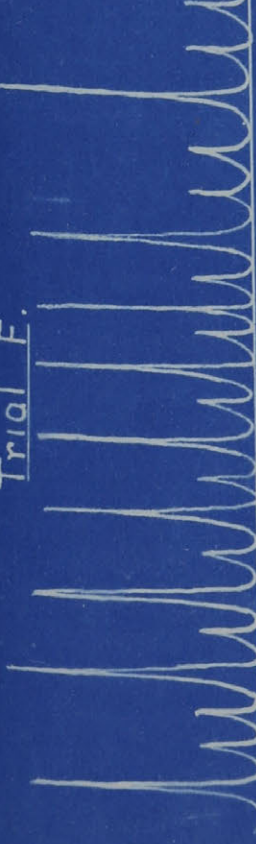
Av. Max.
Press.
183 lbs.
Fuel Cons.
1.04 Lbs

Trial L.



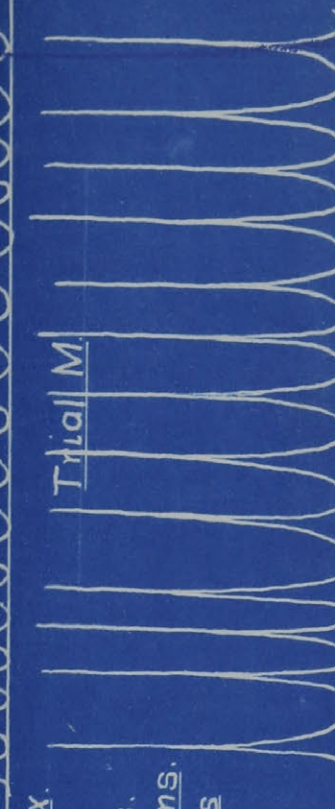
Av. Max.
Press.
273 lbs.
Fuel Cons.
955 lbs.

Trial F.



Av. Max.
Press.
201 lbs.
Fuel Cons.
1.18 Lbs

Trial M.



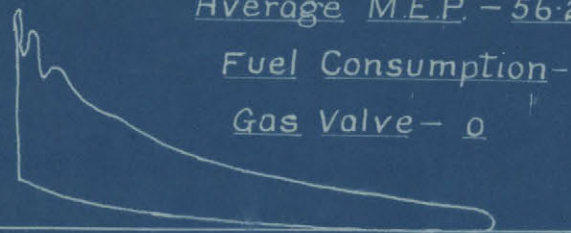
Av. Max.
Press.
272 lbs.
Fuel Cons.
972 lbs.

Trial A

Average M.E.P. - 56.2

Fuel Consumption -

Gas Valve - 0

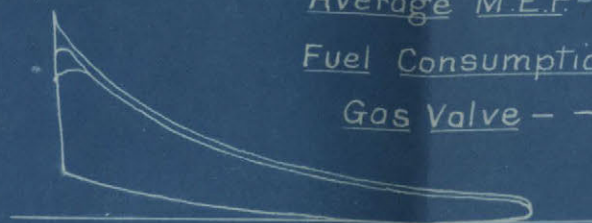


Trial E

Average M.E.P. - 49.2

Fuel Consumption - 1.04

Gas Valve - $-\frac{2}{6}$

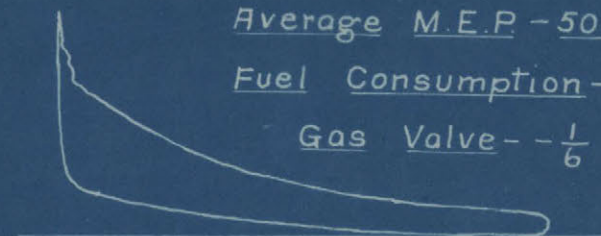


Trial I.

Average M.E.P. - 50.6

Fuel Consumption - .924

Gas Valve - $-\frac{1}{6}$

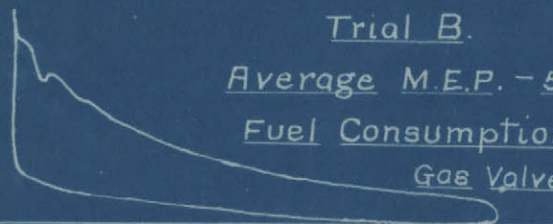


Trial B.

Average M.E.P. - 58.5

Fuel Consumption - 1.05 lbs

Gas Valve - 0

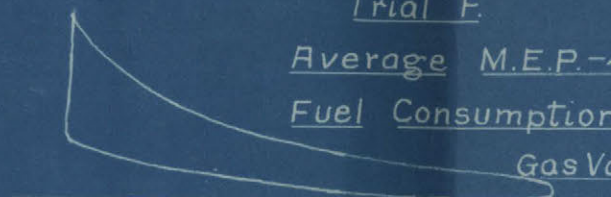


Trial F.

Average M.E.P. - 48.5

Fuel Consumption - 1.18

Gas Valve - $-\frac{2}{6}$

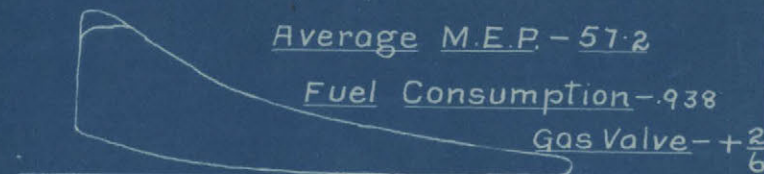


Trial J.

Average M.E.P. - 57.2

Fuel Consumption - .938

Gas Valve - $+\frac{2}{6}$

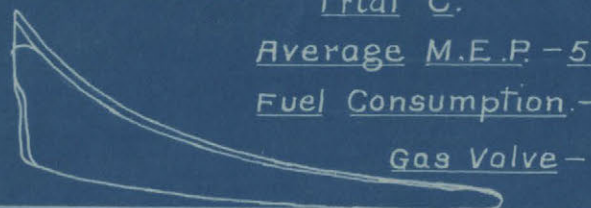


Trial C.

Average M.E.P. - 57.5

Fuel Consumption - .97

Gas Valve - $-\frac{1}{6}$

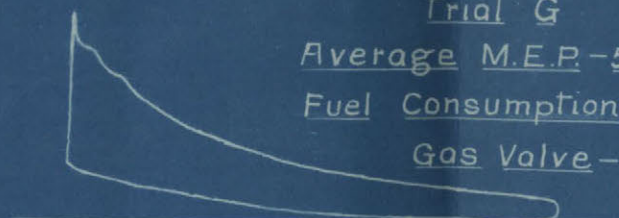


Trial G

Average M.E.P. - 53.3

Fuel Consumption - 1.35

Gas Valve - 0

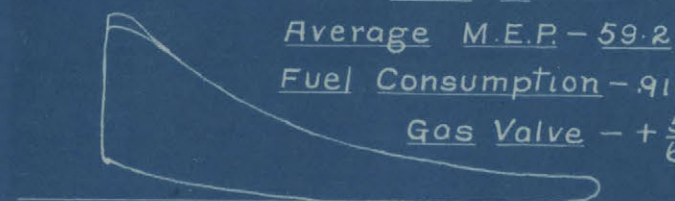


Trial K.

Average M.E.P. - 59.2

Fuel Consumption - .918

Gas Valve - $+\frac{5}{6}$

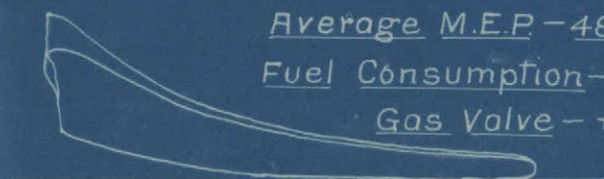


Trial D.

Average M.E.P. - 48.4

Fuel Consumption - 1.002

Gas Valve - $+\frac{1}{6}$

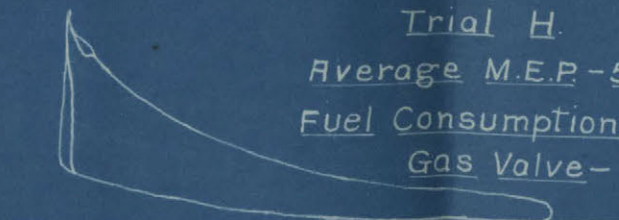


Trial H.

Average M.E.P. - 57.5

Fuel Consumption - 1.30

Gas Valve - $+\frac{1}{6}$



Trial L

Average M.E.P. - 63.

Fuel Consumption - .955

Gas Valve - +2

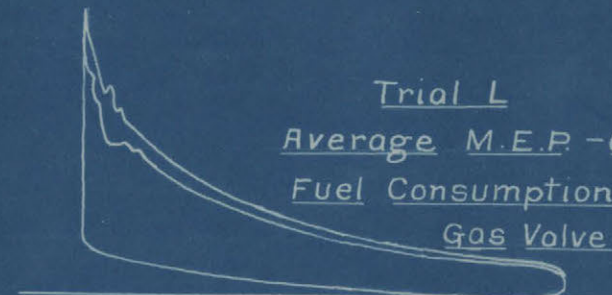
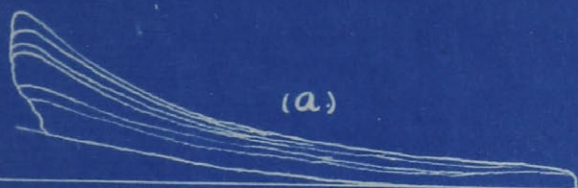
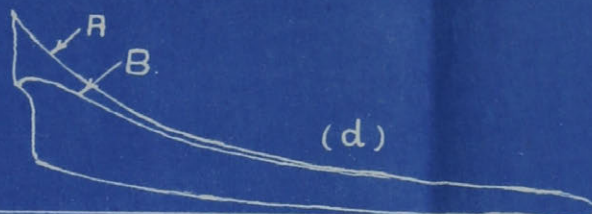


PLATE B.

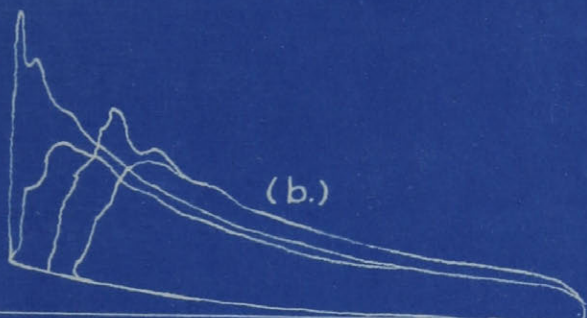
Typical Cards Taken During Tests Using Coal Oil as Fuel. Scale 200 Lbs = 1 Inch.



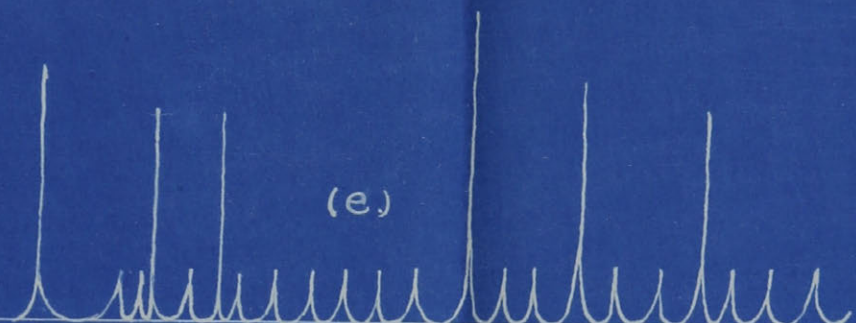
Using Normal Valve Setting
For Coal Oil.



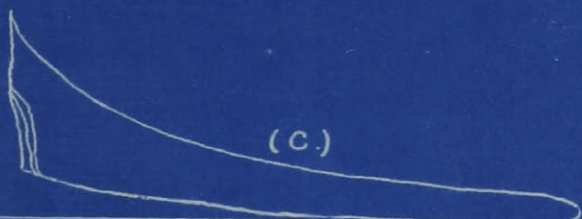
A - Air Valve Closed.
B - Air Valve Open.



Using a stronger gas mixture
than that used in taking (a)



Showing the irregularity of the explosion
when using (b) mixture.



Effect of still further strengthening
the mixture. Plate C.



Card obtained in later trials when
using spark ignition.

Cards Taken When First Experiments Were Made Using Alcohol as Fuel.

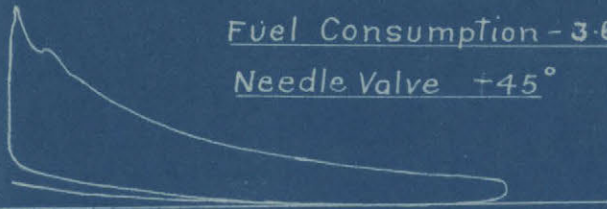
Scale 200 lbs. = 1 Inch

Trial A.

M.E.P. - 68.2

Fuel Consumption - 3.60

Needle Valve +45°



Trial G.

M.E.P. - 70.5

Fuel Consumption - 2.5

Needle Valve - 0°



Trial P.

M.E.P. - 78.3

Fuel Consumption - 2.36

Needle Valve +125°

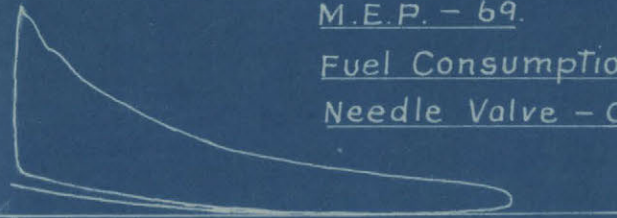


Trial B.

M.E.P. - 69.

Fuel Consumption - 3.80

Needle Valve - 0



Trial H.

M.E.P. - 72.1

Fuel Consumption - 2.65

Needle Valve +45°

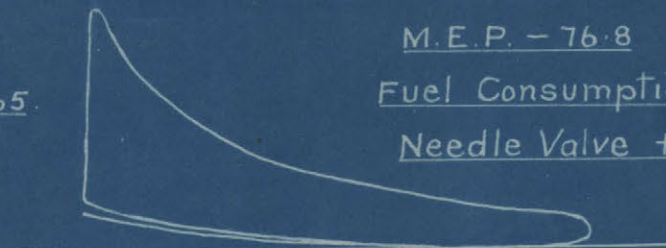


Trial O.

M.E.P. - 76.8

Fuel Consumption - 2.14

Needle Valve +90°

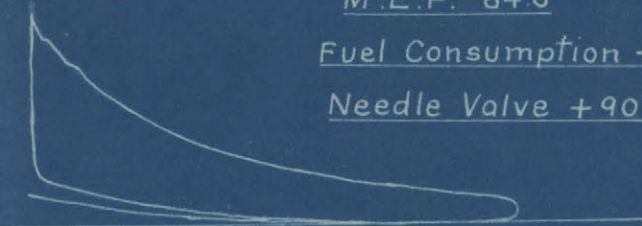


Trial E.

M.E.P. 64.3

Fuel Consumption - 4.05

Needle Valve +90°



Trial L.

M.E.P. - 73.7

Fuel Consumption - 2.06

Needle Valve +135°

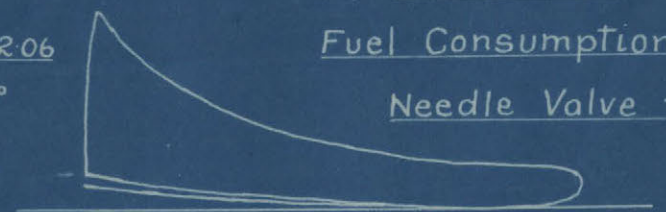


Trial N.

M.E.P. - 71.3

Fuel Consumption - 2.02

Needle Valve +45°

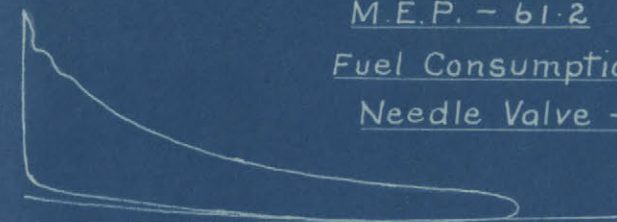


Trial F.

M.E.P. - 61.2

Fuel Consumption - 3.18

Needle Valve - 45°

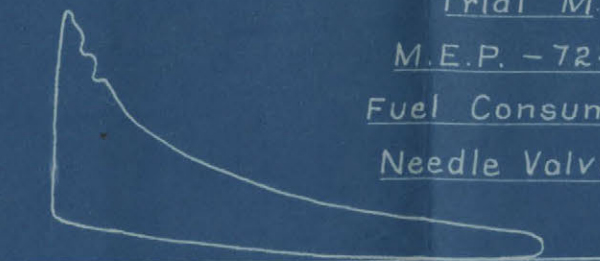


Trial M.

M.E.P. - 72.1

Fuel Consumption - 2.27

Needle Valve +180°



Trial Q.

M.E.P. - 69.3

Fuel Consumption - 2.76

Needle Valve +60°

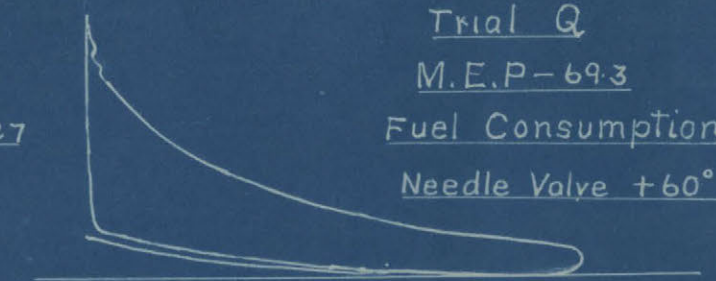


PLATE D

Typical Cards Taken During Tests Using Alcohol as Fuel

Scale 200 Lbs = 1 Inch.

G.K.G.

PLATE E

Using Alcohol as Fuel.

Scale - 200 lbs = 1 Inch

Trial A.

Av. Max.
Press. 202 Lbs.
Fuel - 3.60 Lbs

Trial K

Av. Max.
Press. 224 Lbs.
Fuel - 2.21 Lbs.

Trial E.

Av. Max.
Press. 249 Lbs.
Fuel - 4.05 Lbs

Trial M.

Av. Max.
Press. 198 Lbs.
Fuel - 2.27 Lbs.

Trial G

Av. Max.
Press. 248 Lbs.
Fuel - 2.50 Lbs.

Trial N.

Av. Max.
Press. 215 Lbs
Fuel - 2.02 Lbs.

Trial L

Av. Max.
Press. 256 Lbs.
Fuel - 2.88 Lbs.

Trial O.

Av. Max.
Press. 207 Lbs
Fuel - 2.14 Lbs.

Trial J.

Av. Max.
Press. 183 Lbs
Fuel - 2.32 Lbs.

Trial P.

Av. Max.
Press. 208 Lbs.
Fuel - 2.36 Lbs

BLACKSTONE OIL ENGINE

RESULTS OF TESTS USING "PRIME WHITE" CANADIAN OIL AS FUEL.

MCGILL UNIVERSITY 1909.

TRIAL MARK	A	B	C	D	E	F	G	H	I	J	K	L	M	
DURATION OF TEST	20	20	20	20	20	20	20	20	20	20	20	20	20	Mins
TOTAL REVS PER HOUR	16280	15880	15720	15680	15579	15900	15780	15700	15400	15250	15300	16000	15750	N
TOTAL FUEL PER HOUR	.70	1.915	1.75	1.80	1.87	1.104	1.257	1.203	2.56	2.47	2.70	3.37	3.33	Lbs.
COOLING WATER PER HOUR	165	109.5	93	64.5	108.4	72	67.9	116.3	177	234	219	322.5	310.5	Lbs
TEMP. OF C.W. INLET	78.9	82	62.8	64.2	66.2	75.9	78.2	76.1	51.2	49.6	48.2	41.5	43	°F
DO OUTLET	130.7	163	161	145	155	170	172	153.5	154	160	141.8	136.6	126	°F
MEAN R.P.M.	271.5	265	262	261	260	265	263	262	257	254	256	266.9	263	
IGNITIONS PER MIN.	30.8	89	89.4	84.6	100.5	61.05	56.7	53.9	117.9	122.5	116.1	124.7	125.9	
MEAN EFFECTIVE PRESSURE	56.2	58.5	57.6	48.2	49.4	48.4	53.3	57.5	50.6	52.2	59.2	63	59.1	Lbs. □"
INDICATED HORSE POWER	.934	2.81	2.78	2.46	2.68	1.59	1.63	1.67	32.2	3.45	3.72	4.23	4.02	
EFFECTIVE BRAKE LOAD	0	55.5	55.5	55.5	55.5	28.5	28.5	28.5	85.5	85.5	85.5	105.5	105.5	Lbs.
BRAKE HORSE POWER	0	1.82	1.805	1.795	1.79	.937	.930	.926	2.73	2.69	2.72	3.49	3.43	
FUEL PER I.H.P. - HOUR	.817	.682	.63	.73	.667	.792	.771	.72	.795	.715	.725	.800	.83	Lbs.
FUEL PER B.H.P. - HOUR	—	1.05	.99	1.002	1.04	1.18	1.352	1.30	.937	.918	.983	.955	.972	Lbs.
FUEL PER IGNITION	.000389	.00038	.000335	.00032	.00031	.00030	.000375	.000373	.000363	.000337	.000388	.00045	.00044	Lbs.
HEAT SUPPLIED PER IGN.	7.24	7.01	6.24	5.90	5.77	5.62	6.98	6.94	6.74	6.27	7.22	8.39	8.20	B.T.U.'s
WORK DONE PER IGN.	1.38	1.34	1.32	1.11	1.13	1.11	1.22	1.31	1.16	1.20	1.36	1.43	1.35	B.T.U.
EXHAUST & RADIATION LOSS	5.86	5.67	4.92	4.79	4.64	4.51	5.76	5.63	5.58	5.07	5.86	6.96	6.85	B.T.U.
THERMAL EFFICIENCY	19.	19.1	21.2	18.8	19.6	19.8	17.5	18.9	17.2	19.2	18.8	17.1	16.5	%
COST PER B.H.P. - HOUR	—	2.22	2.09	2.11	2.20	2.49	2.85	2.75	1.98	1.94	2.08	2.02	2.05	Cts
GAS VALVE SETTING	0	0	$-\frac{1}{6}$	$+\frac{1}{6}$	$-\frac{2}{6}$	$-\frac{2}{6}$	0	$+\frac{1}{6}$	$-\frac{1}{6}$	$+\frac{2}{6}$	$+\frac{5}{6}$	+2	$+\frac{2}{6}$	Turns G.L.G.

BLACKSTONE OIL ENGINE

RESULTS OF TESTS USING WOOD ALCOHOL & METHYLATED SPIRITS AS FUEL

MCGILL UNIVERSITY 1909.

TRIAL MARK	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	
DURATION OF TEST	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	Mins.
TOTAL REVS. PER HOUR	16340	16300	15900	16300	16320	14570	15520	15630	15550	13800	15510	16030	15510	15730	15340	15380	15140	
TOTAL FUEL PER HOUR	3.22	3.5	3.64	3.77	3.64	5.13	4.28	4.59	4.95	5.54	5.93	5.70	6.08	5.51	5.68	6.26	4.62	Lbs.
TOTAL IGNITIONS PER HOUR	4070	3940	3630	4040	3820	6480	4920	4840	4960	6660	6000	6180	6270	6150	6100	6010	5060	
KIND OF FUEL USED	W.A.	W.A.	W.A.	W.A.	W.A.	W.A.	W.A.	W.A.	W.A.	W.A.	W.A.	W.A.	W.A.	M.S.	M.S.	M.S.	M.S.	
% OF RATED POWER.	22.5	22.4	23.5	22.4	22.8	40.3	42.8	43.3	43.0	59.5	67.0	69.0	67.0	68.0	66.2	66.2	41.8	%
MEAN R.P.M.	272.4	272.	265.8	272.	273.	243.1	259.1	261.1	259.6	230.	258.9	267.6	258.8	262.6	256.	256.4	252.1	
IGNITIONS PER MINUTE	67.8	65.7	60.5	67.3	63.7	108.	82.0	80.7	82.6	111.	100.	103	104.5	102.5	101.8	100.1	84.3	
MEAN EFFECTIVE PRESSURE	68.2	69.	72.2	64.3	64.3	61.2	70.5	72.1	65.8	60.5	69.8	73.7	72.1	71.3	76.8	78.3	69.3	Lbs./sq"
INDICATED H.P.	2.50	2.45	2.32	2.33	2.21	3.56	3.12	3.14	2.93	3.62	3.76	4.09	4.06	3.95	4.15	4.22	3.15	
EFFECTIVE BRAKE LOAD	26.5	2.65	28.5	26.5	26.5	53.5	53.5	53.5	53.5	83.5	83.5	83.5	83.5	83.5	83.5	83.5	53.5	Lbs.
BRAKE H.P.	.897	.895	.94	.895	.898	1.61	1.71	1.73	1.72	2.38	2.68	2.76	2.68	2.72	2.65	2.65	1.67	
FUEL PER I.H.P. HOUR	1.28	1.43	1.58	1.62	1.65	1.44	1.37	1.46	1.69	1.53	1.58	1.39	1.50	1.39	1.37	1.49	1.47	Lbs.
FUEL PER B.H.P. HOUR	3.60	3.80	3.87	4.22	4.05	3.18	2.50	2.65	2.88	2.32	2.21	2.06	2.27	2.02	2.14	2.36	2.76	Lbs.
FUEL PER IGNITION	.000791	.00089	.00101	.000936	.000953	.000792	.000872	.00095	.00100	.000834	.00099	.000925	.000972	.000899	.000935	.00105	.000914	Lbs.
HEAT SUPPLIED PER IGN.	6.88	7.75	8.78	8.15	8.30	6.88	7.58	8.27	8.60	7.25	8.61	8.05	8.45	8.91	9.26	10.4	9.05	B.T.U.
WORK DONE PER IGN.	1.56	1.58	1.62	1.47	1.47	1.40	1.61	1.65	1.51	1.38	1.59	1.68	1.64	1.63	1.73	1.78	1.59	B.T.U.
EXHAUST & RADIATION LOSS.	5.32	6.17	7.16	6.68	6.83	5.48	5.97	6.62	7.09	5.88	7.02	6.37	6.81	7.28	7.53	8.62	7.46	B.T.U.
THERMAL EFFICIENCY	22.6	20.4	18.5	18.0	17.7	20.3	21.2	20.0	17.6	19.0	18.5	20.9	19.4	18.3	18.7	17.1	17.6	%
COST PER B.H.P. HOUR	39.9	42.2	42.9	46.7	44.9	35.2	27.7	29.3	31.9	25.7	24.5	23.8	25.2	27.2	29.8	31.8	37.2	Cts.
AIR VALVE SETTING					Fully	closed	during	all trials.	Electric	Ignition used								
NEEDLE VALVE SETTING.	-45°	0°	+30°	+45°	+90°	-45°	0°	+45°	+90°	+30°	+90°	+135°	+180°	+45°	+90°	+125°	+60°	GLG.

