THE UTILIZATION OF POWER ALCOHOL IN COMBINATION WITH NORMAL AND HEAVY FUELS IN HIGH SPEED DIESEL ENGINES

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Summary

Power Alcohol can be utilised in Diesel engines by being blended to the normally accepted Diesel fuels or preferably, it can be carburetted. The report deals with the possibilities and limitations of these two methods in the light of the necessity to use a high percentage of Alcohol in combination with normal, or preferably, lower grade fuels, in high speed Diesel engines. Carburetion of Power Alcohol allows 60% of alcohol to be utilised with heavier types of fuels than usually accepted in high speed engines, and higher percentages are possible in combination with groundnut oil, and permits such engines to be over-loaded upto 40–45%.

1. Introduction

1.1. *General.*—The development of a method to use Power Alcohol in combination with cheaper low grade fuels is interesting from a technical point of view as it allows to use heavier fuels in high speed Diesel engines. It is also interesting economically since Power Alcohol is sometimes available in considerable quantities as an indigenous fuel, for which the opening of an additional usage may be an economically progressive step.

1.2. *Technical.*—Power Alcohol has been used for a number of years as a blending medium with automotive petrol, although its low calorific value diminishes the heat value of the blend and thus the percentage of alcohol will have to be limited somewhat. There is also the further limitation in obtaining complete miscibility of petrol and larger percentages of alcohol due to possible traces of water in the mixture. Miscibility is further adversely affected by low ambient temperatures. Figs. 1[1] and 2[2] illustrate these points clearly. It is shown in Fig. 1 that even as little as 0·1% of water will lead to separation of blends containing 5% of alcohol at 15° C. In blends having 15% of alcohol—which is the usual practice—even 0·6% of water will result in separation. As the percentage of alcohol increases tolerance towards water will improve but the net calorific value of the blend falls and this is by no means a desirable feature. It is seen from Fig. 2 that the general

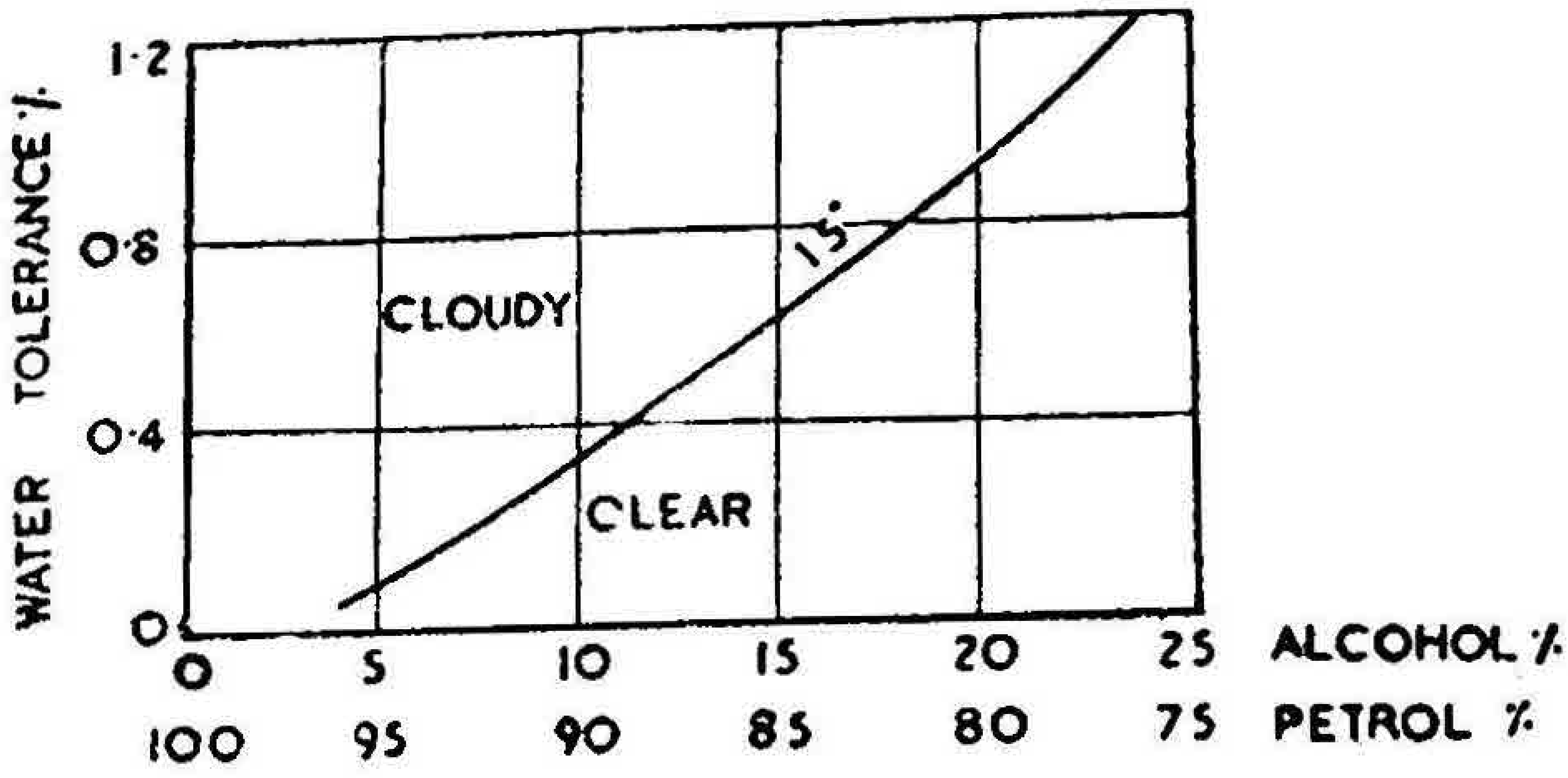


FIG. 1. Water Tolerance of Petrol-Alcohol Blends at 15° C.

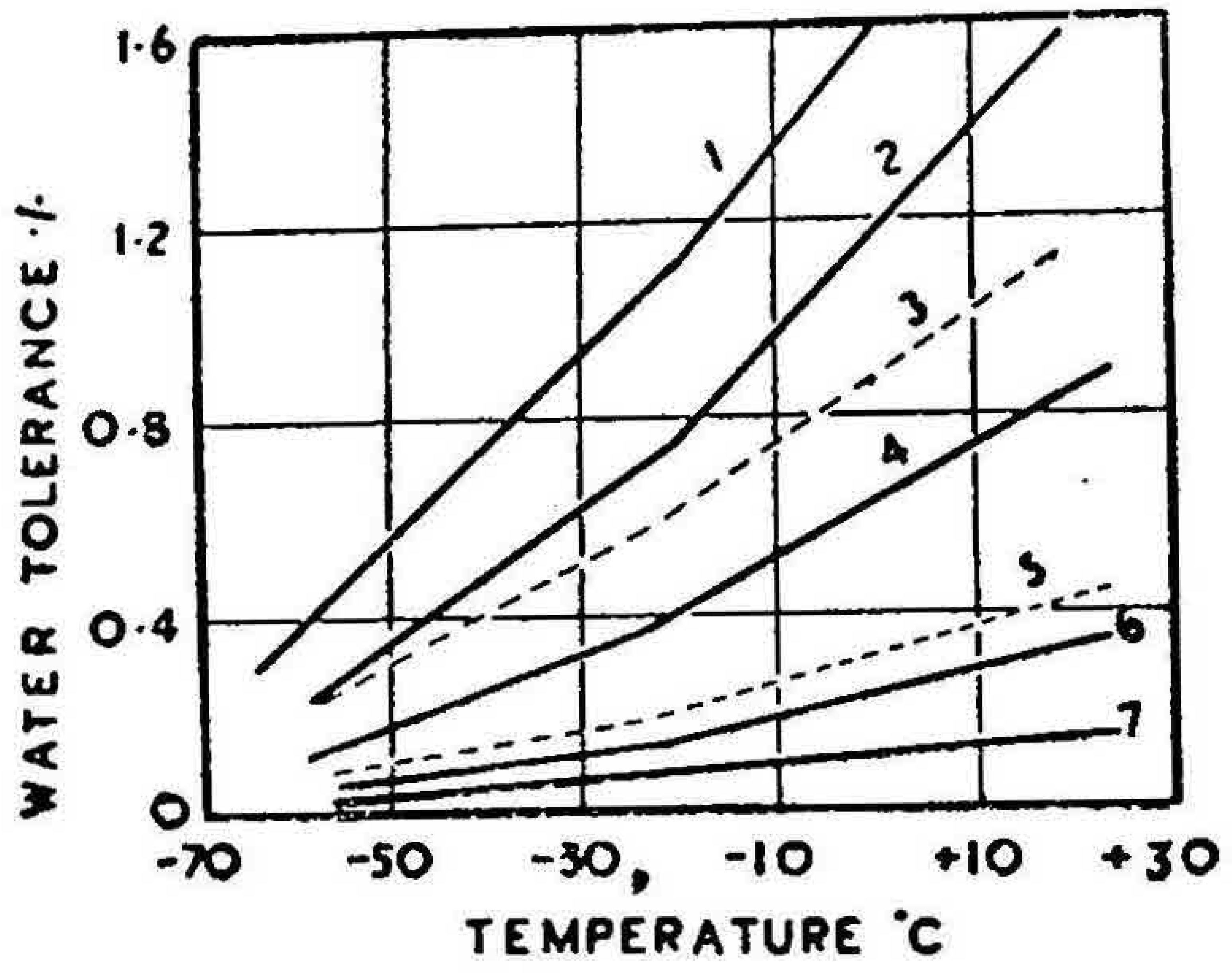


FIG. 2. Water Tolerance and Temperature

(1) 40% Alcohol 60% Petrol
(2) 30% Alcohol 70% Petrol
(3) 20% Alcohol 20% Benzole 60% Petrol
(4) 20% Alcohol 80% Petrol
(5) 10% Alcohol 20% Benzene 70% Petrol
(6) 10% Alcohol 90% Petrol
(7) 5% Alcohol 95% Petrol

water tolerance of all blends of alcohol and petrol will decrease with the decrease in the ambient temperature and this is very noticeable with blends having higher percentages of alcohol.

An additional feature is that hydrocarbons of the paraffin series are much less readily soluble than those of the aromatic series, and the solubility rapidly decreases with increase in molecular weight.

Subject to the above considerations alcohol blended with petrol in small quantities—usually between 15 and 20%—serves as an anti-knock agent, and this property is of sufficient value to overcome the disadvantages of lower heat value of the blend. Blends containing higher percentages of alcohol are usually ruled out.

From the foregoing it is clear that there is a limitation to the use of alcohol in petrol engines. Even within these limitations alcohol belnds are employed to less advantage in the commercial petrol engines since the anti-knock properties of the blends are not fully utilised in such engines.

The aim of the investigation was therefore to use alcohol in some engine of common design having higher compression ratio and accepting alcohol in much higher proportions than are employed at present, and overcoming the limitations set by water tolerance.

Another problem which was receiving serious consideration at the same time, and originally independently, was the utilization of heavy hydrocarbon fuels in high speed Diesel engines. Heavy hydrocarbon fuels are generally employed in slow speed engines and they are cheaper than the high speed Diesel oil.

There are, however, two major drawbacks with heavy fuels which make them unsuitable for use in high speed Diesel engines: the combustion process of heavy fuels is sluggish and there is a higher percentage of sulphur. The former results in smoky exhaust and the latter leads to excessive corrosive wear. If a method were found out, which made it possible to use these fuels in high speed Diesel engines, it would constitute a step forward economically and scientifically.

This report outlines methods by which the first mentioned problem of the utilization of alcohol as such is solved. With their help, it appears that also the answer to the second, the acceptance of low grade fuels in high speed Diesel engines, is established, at least in principle, although further work will be necessary to cover the whole field in both aspects.

2. REVIEW OF PREVIOUS WORK

Considerable research has been conducted by a number of workers to find ways and means of using the heavier and residual fuels in place of superior distillates. These activities can be broadly classified under two heads:

(1) Improving the ignition quality of the fuel.

(2) Minimising the deleterious effects of high sulphur and carbon residues.

2.1. *Ignition Quality of the Fuel.*—Regarding the ignition quality of the fuel, it was first shown by Ricardo[3] that it could be improved by the addition of small proportions of certain chemical substances. These additives are supposed to expedite the ignition of the fuel by reducing the temperature of self-ignition. Amyl nitrate, ethyl nitrate and acetone peroxide are a few of the many ignition accelerators that are found suitable for blending with Diesel fuels of low cetane value. One of the practical objections to these accelerators is the high cost and another is the effect of the additives on engine life. Not much is known about the latter aspect. Also the effect of an accelarator decreases as its proportion is increased; that is to say, an addition of 2% will not increase the cetane number twice as much as an addition of 1%.

A second line of attack on the problem of improving combustion is constituted by supercharging the engine. In a recent address, Ricardo[4] has given particulars of tests which he has carried out on an engine running at 1500–2000 R.P.M. With a pressure boost of half an atmosphere, the engine ran smoothly on a fuel having a cetane number as low as 18. This may, no doubt, be a good remedy but this will also put up the cost of the basic engine unit as well as the cost of maintenance. The air utilization factor, however, does not vary much.

In addition to the investigation undertaken by Ricardo, the following researches have become known:

McLaughlin[5] and his associates report that combustion in a high speed Diesel engine could be accelerated by carburetting volatile fuel having high self-ignition temperature. Advantage can be taken of this phenomenon either to reduce the exhaust smoke density of an engine or for the same smoke density, boost the engine power by some 20%. Maxwell of Caterpillar Corporation found that, by carburetting mixtures of alcohol and water in a supercharged Diesel engine, the efficiency could be slightly improved as also the power output.

Young of the Sinclair Research Laboratories found that fuels that require a compression ratio of 25: 1 could have satisfactory combustion at a compression ratio of 12: 1 by carburetting some 5% of *n*-Heptane. By a similar method, the author could burn in the engine distillate fuels with as low a cetane value as 12 and the performance was as good as that of Diesel fuels having a cetane value of 50. H. M. Gadebusch of General Motors also reported similar results.

Hobbs[6] has found that, when added to a normal Diesel fuel, alcohol tends to reduce shock loading on ignition, improves combustion and reduces smoke density. Aubert has found similar results, when using Diesel oil and ethanol in a dual injection engine.

2.2. *Deleterious Effects of Residual Matter.*—Regarding the deleterious effects of high sulphur and carbon contents in heavy fuels, Brewer and Thorp[7] have shown that, for medium speed engines, the use of heavier fuels leads to injector nozzle incrustations. Cylinder wear and crankcase fouling are slightly increased.

J. R. P. Smith[8] has also noticed similar effects when medium speed engines are run on heavy fuels.

In the case of large slow speed engines, Lamb[9] reports that there is little or no increase in the rate of liner wear or carbon deposit resulting from a change to residual fuel.

In the case of a high speed engine (5 B.H.P. at 1500 R.P.M.), A. Natarajan and M. R. K. Rao[10] find that there is a noticeable increase in the wear of the liner and top ring as well as an increase in the carbon deposit when the fuel is changed from B.S.S. Grade A to B.S.S. Grade B fuel. The tendency for ring sticking is also more pronounced in the latter case.

Broeze and Wilson[11] report that sulphur in the fuel aggravates the liner wear problem. C. H. Cloud and A. J. Blackwood[12] of Esso Laboratories have obtained similar results. It is suggested that sulphur, contained in Diesel fuel, burns to sulphur trioxide and the presence of this raises the dew point and causes condensation of aqueous acid products at a higher temperature than can normally be expected. This leads to increased liner wear and sludge formation. It is found that employing chromium-plated liners or piston rings and heavy duty additive type lubricants reduces wear.

2.3. *Conclusions from Previous Work.*—The review thus can be summarised:

1. It has been found in practice that heavier fuels can be burnt successfully in large and medium size engines without the assistance of any ignition accelerators but with the assistance of preheating and purifying of fuel.

In the case of high speed engines, it is necessary however, that some sort of combustion accelerators should be employed in addition to preheating and purifying.

2. Chemical accelerators have not yet become a practical success due to economic and other reasons.

3. Carburetion of suitable quantities of volatile fuels having high self-ignition temperature leads to combustion acceleration and power boosting. This has the additional advantage of a higher air utilization factor.

4. To some extent, blending gasoline or alcohol with Diesel fuel leads to improvement in combustion and performance of the engine.

5. Heavier fuels lead to higher rate of carbon deposits and wear and combustion accelerators may reduce these defects.

6. Chromium plating of liner or top ring and the use of heavy duty lubricants reduce wear.

3. SCOPE OF THE WORK PRESENTED

The foregoing review underlines that heavier hydrocarbon fuels can be used in high speed Diesel engines only if a suitable ignition or combustion accelerator is used. The works of Hobbs, Aubert, McLaughlin and others suggest that alcohol could be used as a successful combustion accelerator. While Hobbs used a blend of alcohol and Diesel fuel in an ordinary engine, Aubert applied a dual injection system in his work and the others used carburettors, etc., for inducting volatile fuels mostly for the purpose of boosting the power output. Consequently, the percentage of the inducted fuel was of a low value. The aim of the present investigation was, however, to find a way of using alcohol as the principal fuel.

At the outset, it was considered that the blending of alcohol with heavy fuel is a comparatively simple process, and acceptable, if successful. In addition to acting as combustion accelerator, alcohol was expected to act as a " thinning agent " and thus would reduce the viscosity of heavy fuels to a value suitable for the injection equipment. The Hobbs-method of blending alcohol with heavier fuels was therefore tried out first. This experiment also gives an answer to the problem of using heavy fuels and at the same time, using alcohol in an engine that can be expected to yield better results than a petrol engine. Since alcohol-Diesel blending did not produce the results anticipated, it was decided to change over to carburetion of alcohol and injection of Diesel fuel.

4. ALCOHOL AS A BLEND WITH DIESEL FUEL IN H.S.D. ENGINES

This work was done in two parts: (1) preparation of the blends, and (2) utilization of the blends in the experimental engines.

4.1. *Preparation of Blends of Alcohol-Diesel Fuels.*—It has been mentioned in the Introduction that (1) anhydrous alcohol can combine in any proportion with hydrocarbon fuels, (2) such solutions have a very low water tolerance, (3) hydrocarbons of the paraffin series are much less readily soluble than those of the aromatic series and (4) the solubility decreases with increase in molecular weight. These conditions hold good for non-volatile hydrocarbon fuels as also for volatile hydrocarbon fuels.

If anything, the difficulties of blending are increased in the case of Diesel fuels in view of the fact that the molecular weight gradually increases as the fuel changes from distillate gas oil to residual oil. Appendix I gives details of the experimental results regarding miscibility of B.S.S. grade A, B.S.S. grade B and furnace oil.

These experiments indicate that Grade A oil is miscible with alcohol to a maximum extent and this is further facilitated by heating the blend to about 60° C. However, traces of water added to the blend, whether cold or hot, separate the components. In the case of Grade B oil blend miscibility is lower and presence of water is more harmful. In the case of furnace oil there is little or no miscibility.

Within these limitations of miscibility blends were prepared containing 10% and 5% alcohol and the rest Grade A or Grade B oil.

4.2. *Engine Tests with Alcohol-Diesel Fuel Blends.*—These blends were used as fuel, first in a Ricardo Research Engine with Diesel head and later in a Kirloskar-Petter High Speed Diesel Engine with precombustion chamber. The results from Ricardo Engine trials are presented graphically in Figs. 3 *a*, 3 *b* and 3 *c*. The tests revealed that there was no noticeable improvement

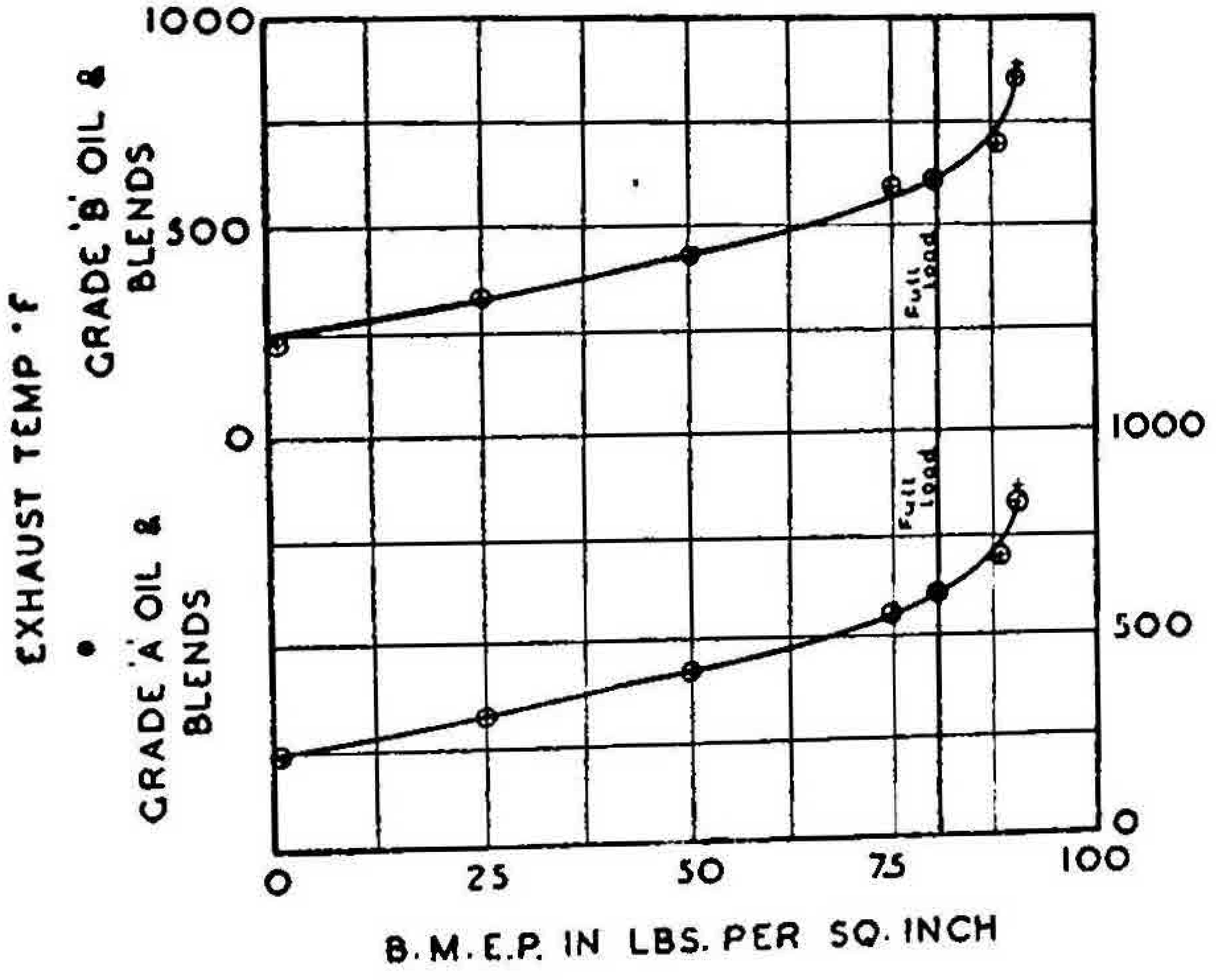


FIG. 3*a*

Ricardo E-6 Engine
Compression Ratio—21·22 : 1; Speed—1250 R.P.M.; Fuels—Neat Grade 'A' and Grade 'B' Oils and Blends with Alcohol
Angle of Advance of Injection—37° Before T.D.C.

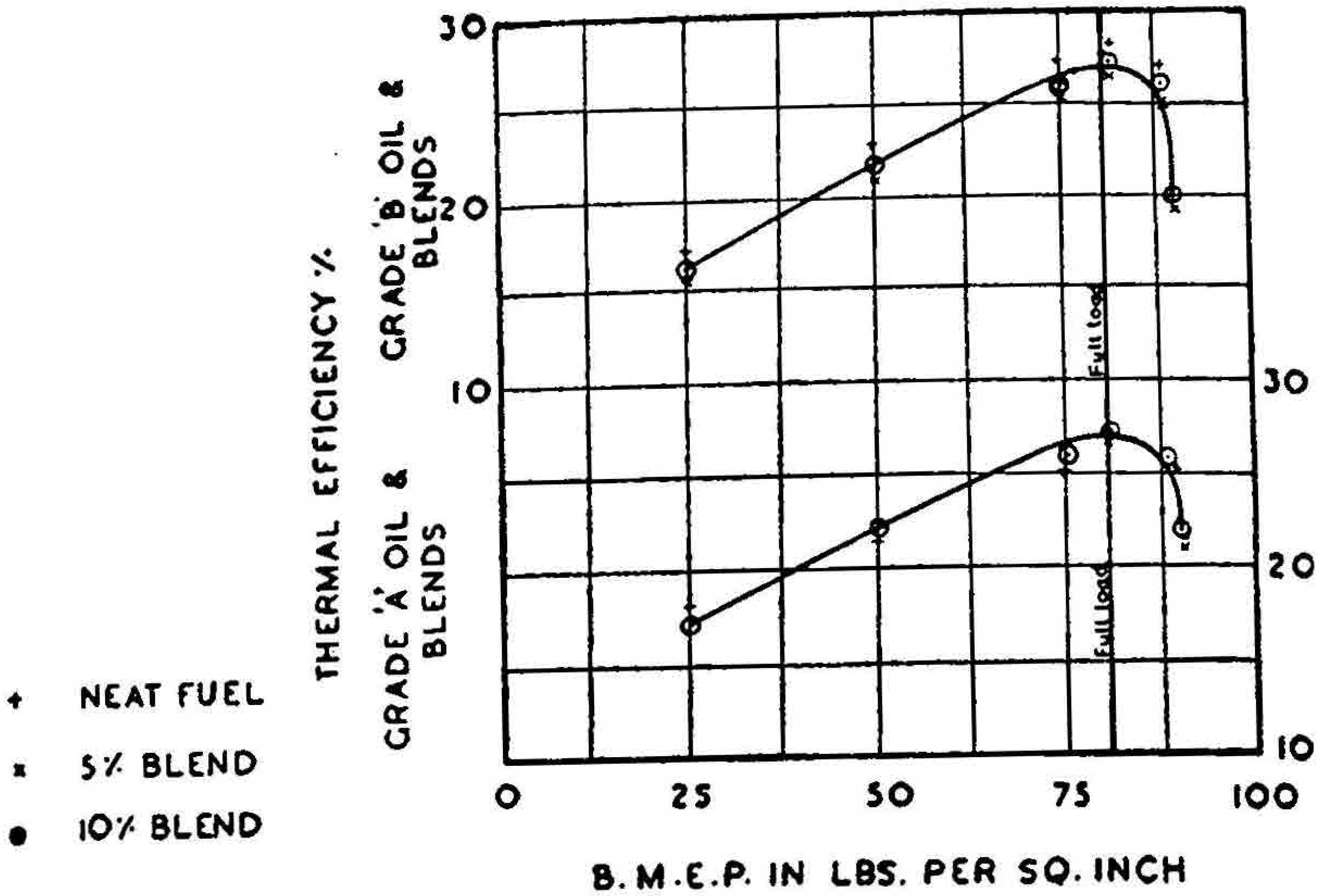


FIG. 3*b*

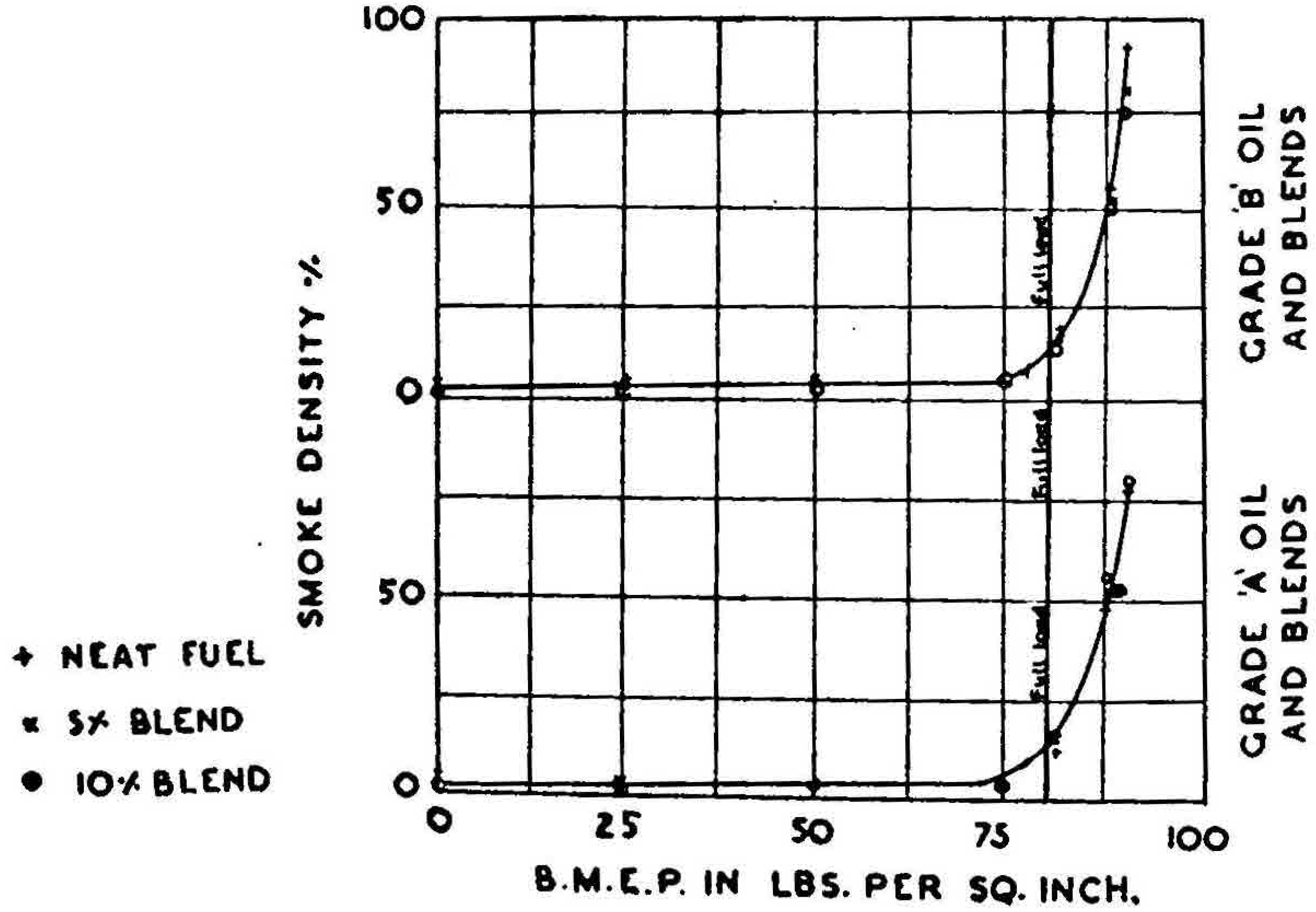


FIG. 3 *c*

Ricardo E-6 Engine
Compression Ratio—21·22 : 1; Speed—1250 R.P.M.; Fuel—Neat Grade 'A' and Grade 'B' Oils and Blends with Alcohol
Angle of Advance of Injection—37° Before T.D.C.

in combustion and exhaust smoke density or in the running properties of the engine. The results from the Kirloskar-Petter Engine trials are omitted since they were similar to the former results.

5. ALCOHOL AS A SUPPLEMENTARY FUEL IN H.S.D. ENGINES

The results obtained with alcohol-Diesel fuel blends—good enough in certain respects—were not exactly what was expected. It was therefore decided to try carburetion of alcohol in combination with injection of different Diesel fuels.

5.1. *Tests with Ricardo Research Engine.*—These tests were limited to injection of Grade B Diesel fuel and carburetion of alcohol.

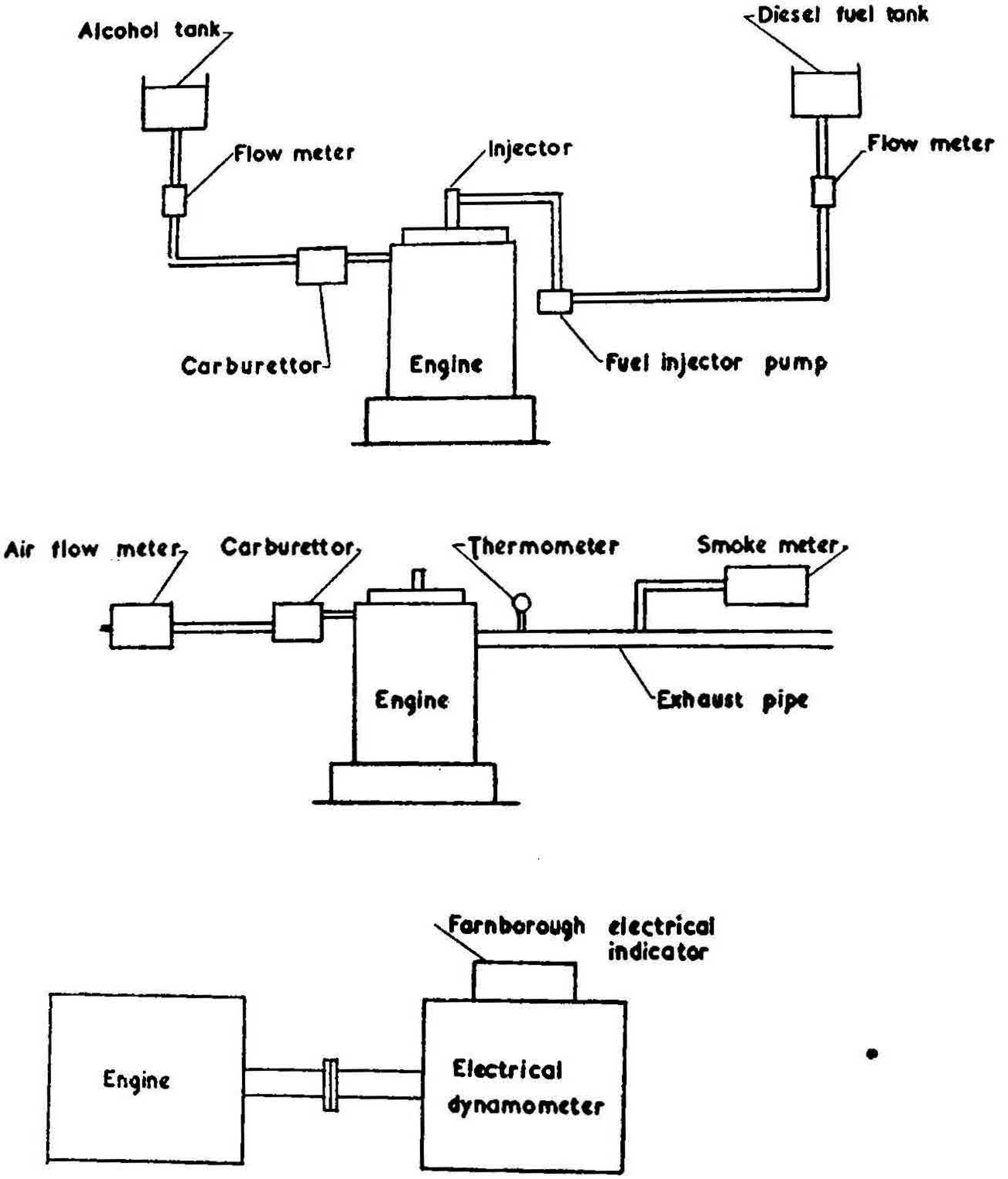
5.11. *Test Set-up.*—The schematic layout of the set-up is indicated in Figs. 4 *a*, 4 *b* and 4 *c* and Table 1 gives specifications of the Ricardo Research Engine. The engine was fitted with the precombustion chamber Diesel head and the head was locked such that the apparent compression ratio was 21·22: 1. Fuel was injected through a pump having suitable attachments to vary injection timing. Alcohol was introduced into the induction manifold, through a variable jet carburettor. Each fuel had a separate flow meter to measure the fuel consumption. The air flow was measured by 'Alcock' viscous flow air meter. A C.R.C. Photoelectric

TABLE 1

Specifications of the Ricardo E-6/R Variable Compression Engine Serial No. 21/46

General details ..	.. Four-stroke, compression ignition, vertical, water cooled
Number of cylinders..	.. 1
Bore diameter ..	.. 3 in.
Stroke	.. 4 $\frac{3}{8}$ in.
Swept volume ..	.. 506 c.c.
Compression ratio used	.. 21·22: 1
Rated power ..	.. 4·2 B.H.P. at 1250 R.P.M.
Tappet clearance—inlet	.. 0·006 in.
exhaust	.. 0·008 in.
Inlet valve opens ..	.. 9° Before top dead centre
Inlet valve closes ..	.. 37° After bottom dead centre
Exhaust valve opens	.. 44° Before bottom dead centre
Exhaust valve closes	.. 5° After top dead centre
Fuel injection pressure	.. 100 atmos.
Fuel injection timing-set	.. 37° Before top dead centre
Injector	.. C.A.V. type DN 12 SD 12
Fuel pump ..	.. C.A.V. type PEIB 5·5 mm. dia. plunger
Combustion chamber	.. Ricardo Comet MK II-compression swirl

smoke meter was used to measure the smoke density. Power measurements were made with a 'Farnborough' electric engine indicator and an electric



ENGINE SET UP FOR TESTING ALCOHOL AS SUPPLEMENTARY FUEL IN RICARDO E-6 ENGINE (DIESEL HEAD)

FIG. 4 *a*

dynamometer. Other standard instruments were used to measure the speed, temperatures, etc.

5.12. *Test Procedure.*—The engine was started on Diesel fuel and allowed to warm up for some time. It was then loaded to a particular value. The injection timing was set at 37° before T.D.C. for optimum results. Cooling water temperature was maintained at 70° C. at exit from engine. At steady running conditions one set of the following readings was taken:

Air and fuel flow meters, speed, brake load, indicator diagram, different temperatures, smoke meter and barometer.

Maintaining the load constant at this value, Diesel fuel was gradually cut down and alcohol inducted in suitable proportions. For each combination of alcohol and Diesel fuel, the engine was run at steady conditions and various observations were recorded as before. Incipient knocking of the

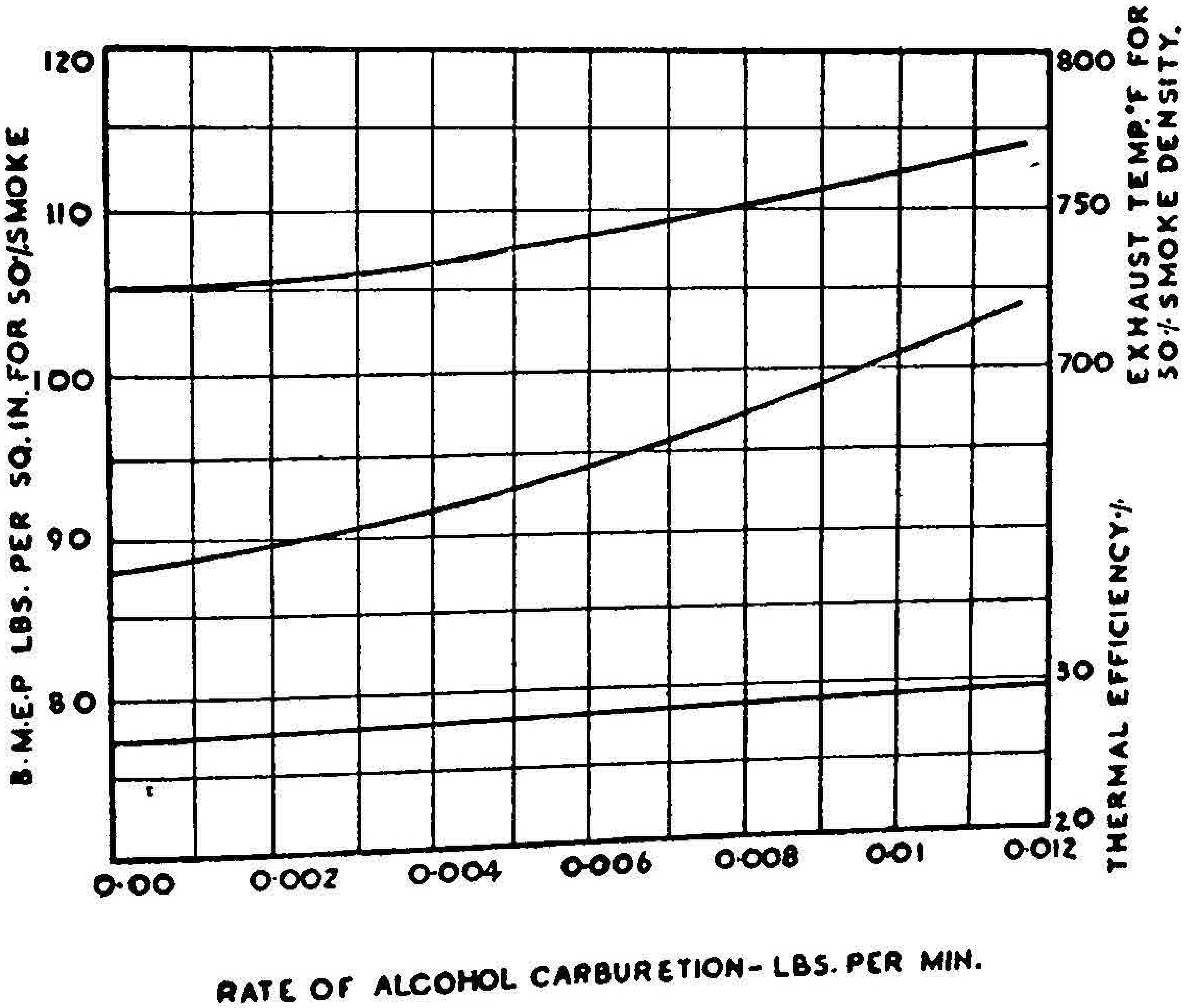


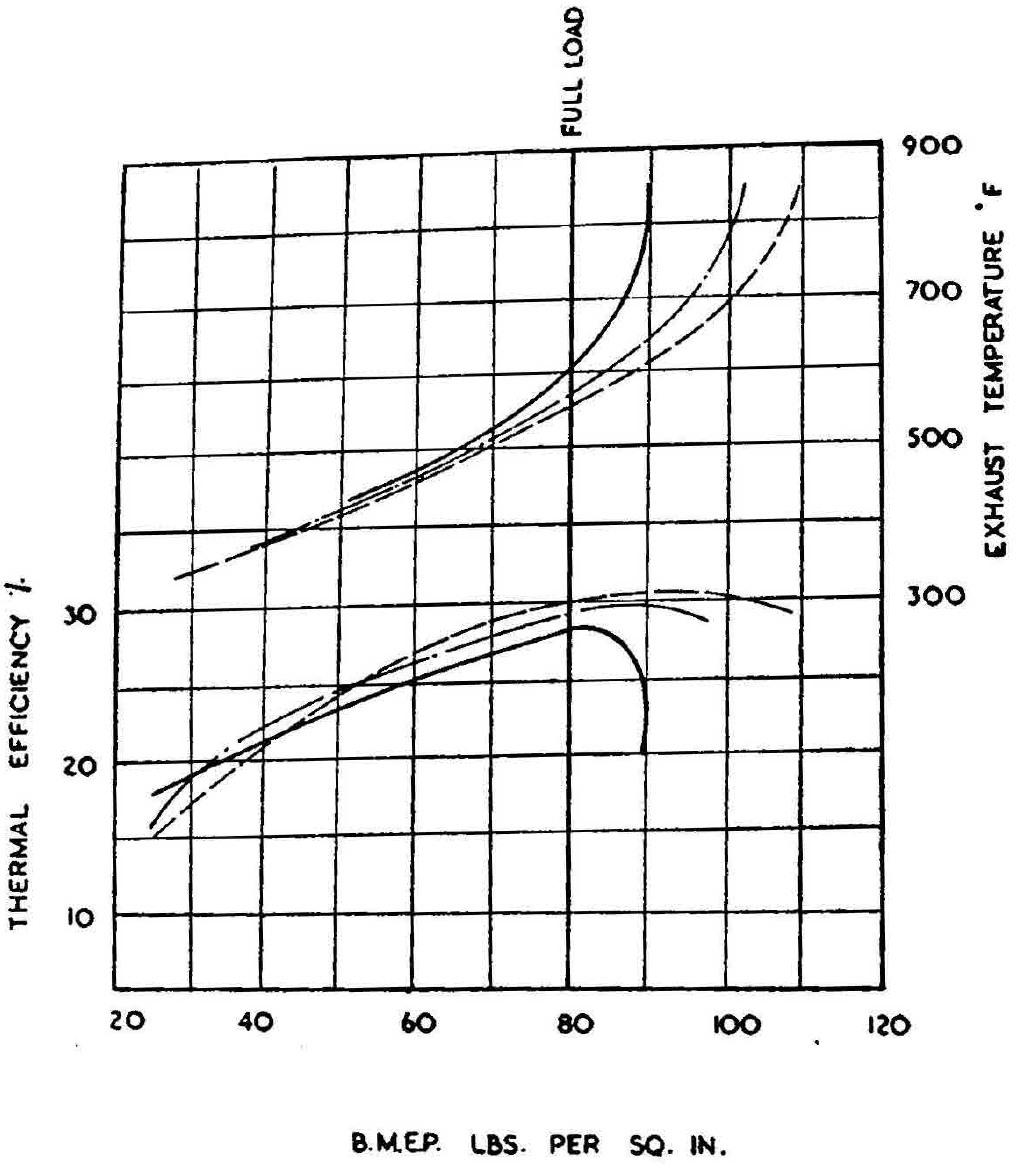
FIG. 5 *a*

Ricardo E-6 Engine

Compression Ratio—21·22 : 1 ; Speed—1250 R.P.M.; Injected Fuel—Grade 'B' Oil

Angle of Advance of Injection—37° Before T.D.C.

engine indicated the upper limit to which the proportion of alcohol could be increased. This procedure was repeated for different loads.



——— GRADE 'B' OIL

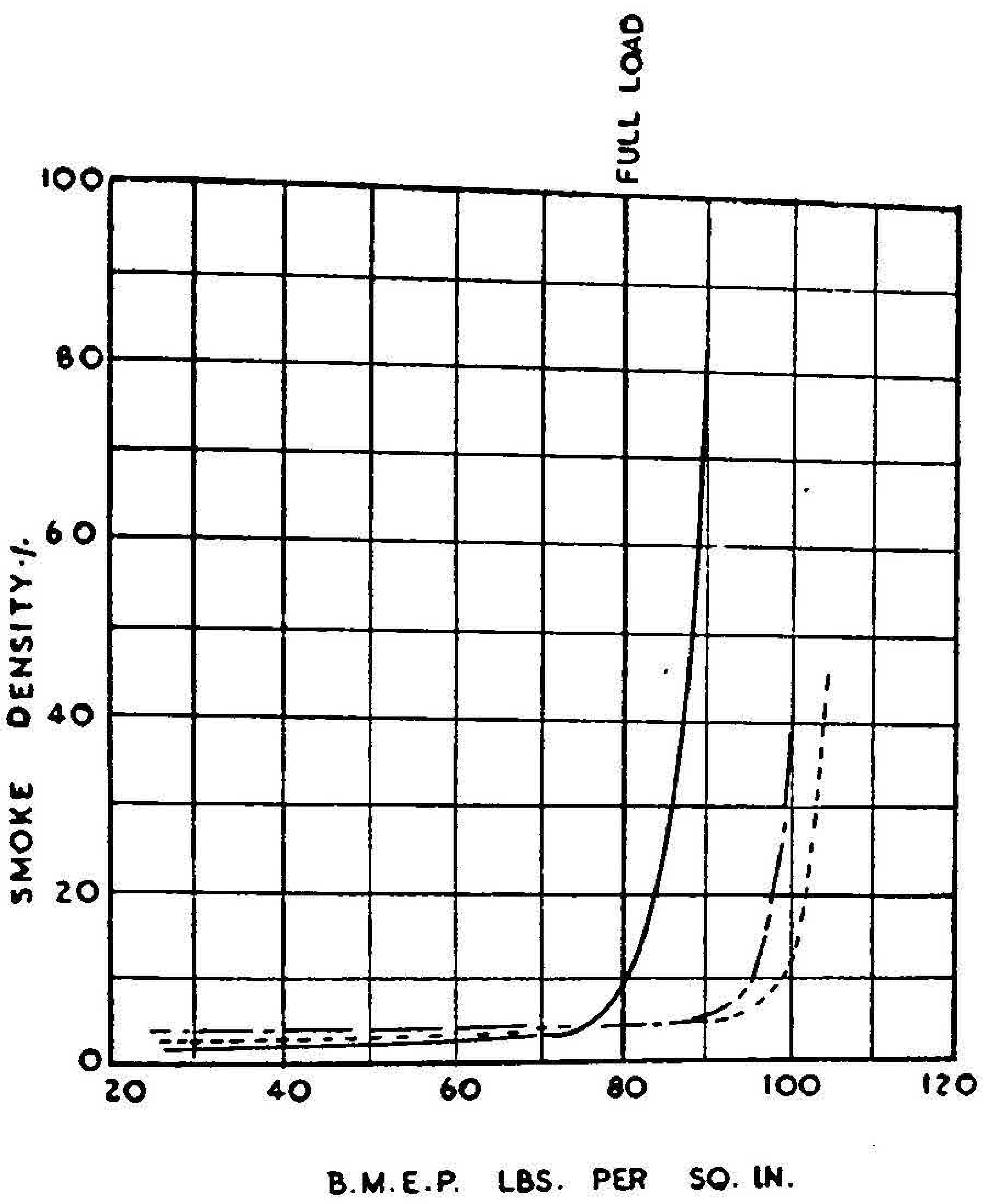
—·— GRADE 'B' OIL WITH ALCOHOL CARBURETION AT 0·01 LBS/MIN

– – – GRADE 'B' OIL WITH ALCOHOL CARBURETION AT 0·012 LBS/MIN

FIG. 5*b*

Ricardo E-6 Engine

Compression Ratio—21·22 : 1; Speed—1250 P.R.M.; Injected Fuel—Grade 'B' Oil
Angle of Advance of Injection—37° Before T.D.C.



——— Grade 'B' oil only

— — — Grade 'B' oil with Alcohol Carburetion at 0·01 lbs./Per Min.

- - - - - - Grade 'B' oil with Alcohol Carburetion at 0·012 lbs./Per Min.

FIG. 5 *c*

Ricardo E-6 Engine

Compression Ratio—21·22 : 1; Speed—1250 R.P.M.; Injected Fuel—Grade 'B' Oil
Angle of Advance of Injection—37° Before T.D.C.

5.13. *Test Results.*—Test results are graphically presented in Figs. 5 *a*, 5 *b*, 5 *c* and 6 *a*, 6 *b*, 6 *c* and summarised below:

1. The maximum quantity of alcohol that could be inducted was 36% of the full load fuel required by the engine. This worked out to be equivalent

to an air alcohol ratio of 54: 1. It was also noticed that the engine started missing, at idling, if the mixture ratio was made richer than 54: 1.

2. The engine could be overloaded by more than 16% as a result of induction of alcohol. Under overload conditions the smoke density was no more than that at full load with neat Diesel fuel (Figs. 5 *a* and 5 *b*).

3. A direct inference from overload characteristics was that the air utilization factor was higher with alcohol induction, as compared to normal running conditions.

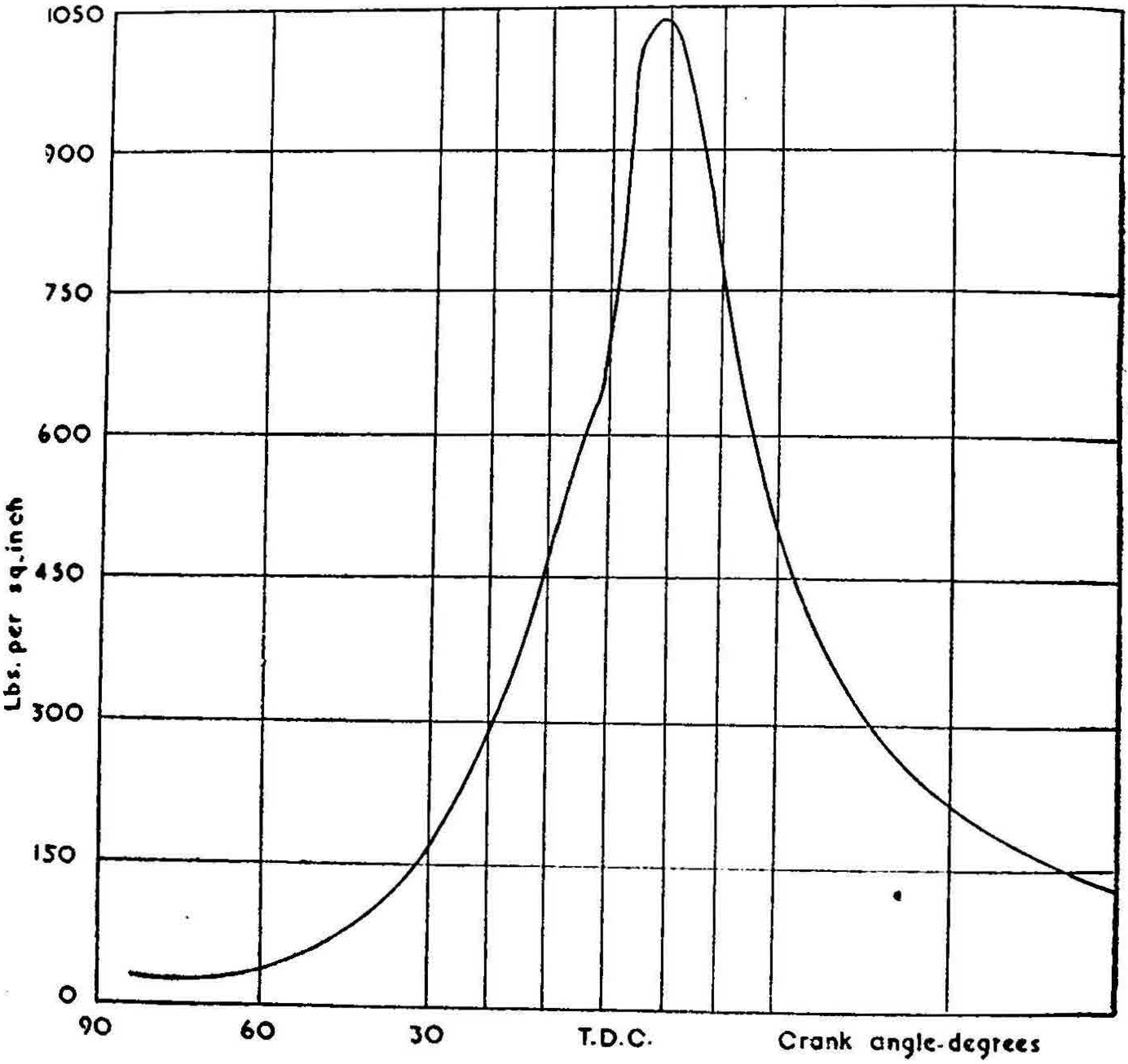


FIG. 6 *a*. Indicator Diagram
Ricardo E-6 Engine
Compression Ratio—21·22 : 1; Speed—1250 R.P.M.; Load—Full Load; Fuel—Grade 'B' Oil
Angle of Advance of Injection—37° Before T.D.C.

4. Except at very light loads, there was a small but distinct increase in thermal efficiency as a result of induction of alcohol. This value increased as the percentage of alcohol inducted increased (Figs. 5 *a* and 5 *b*).

5. There was no perceptible change in the volumetric efficiency.

6. The smoke density was reduced considerably as a result of induction of alcohol. For any particular load the higher is the rate of alcohol inducted, the lower is the smoke density. At full load, with induction of maximum

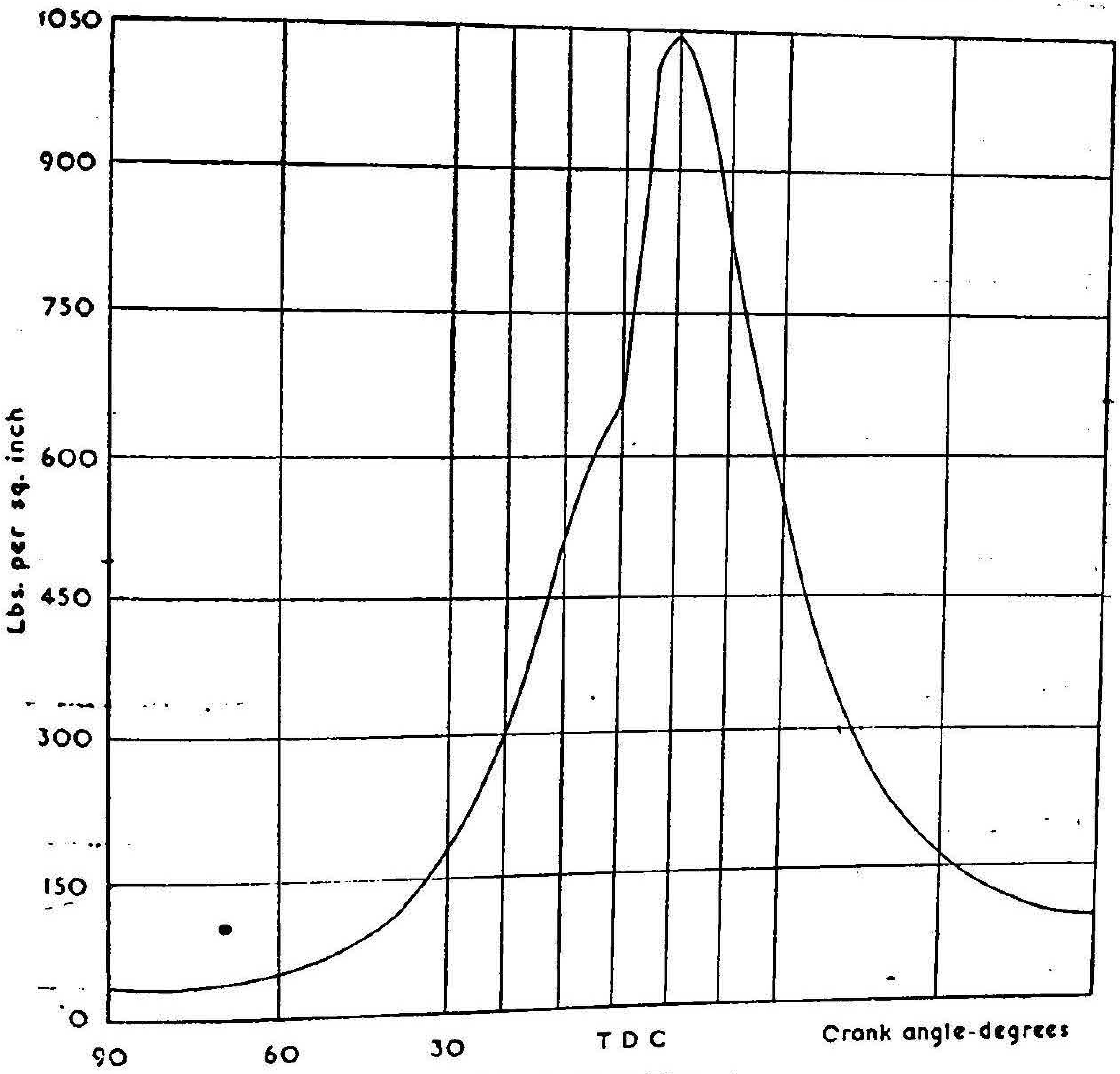


FIG. 6 *b*. Indicator Diagram
Ricardo E-6 Engine
Compression Ratio—21·22 : 1; Speed—1250 R.P.M.; Load—Full Load; Rate of Alcohol—Carburetion 0·010 Lb./Min.
Injected Fuel—Grade 'B' Oil
Angle of Advance of Injection—37° Before T.D.C.

quantity of alcohol the exhaust colour was comparable to that of a petrol engine (Figs. 5 *a* and 5 *c*).

7. There was a distinct drop in the exhaust gas temperature when alcohol was inducted (Figs. 5 *a* and 5 *b*).

5.2. *Tests with a Petter Engine.*—Results obtained from the Ricardo engine trial being promising, the investigation was extended to a production

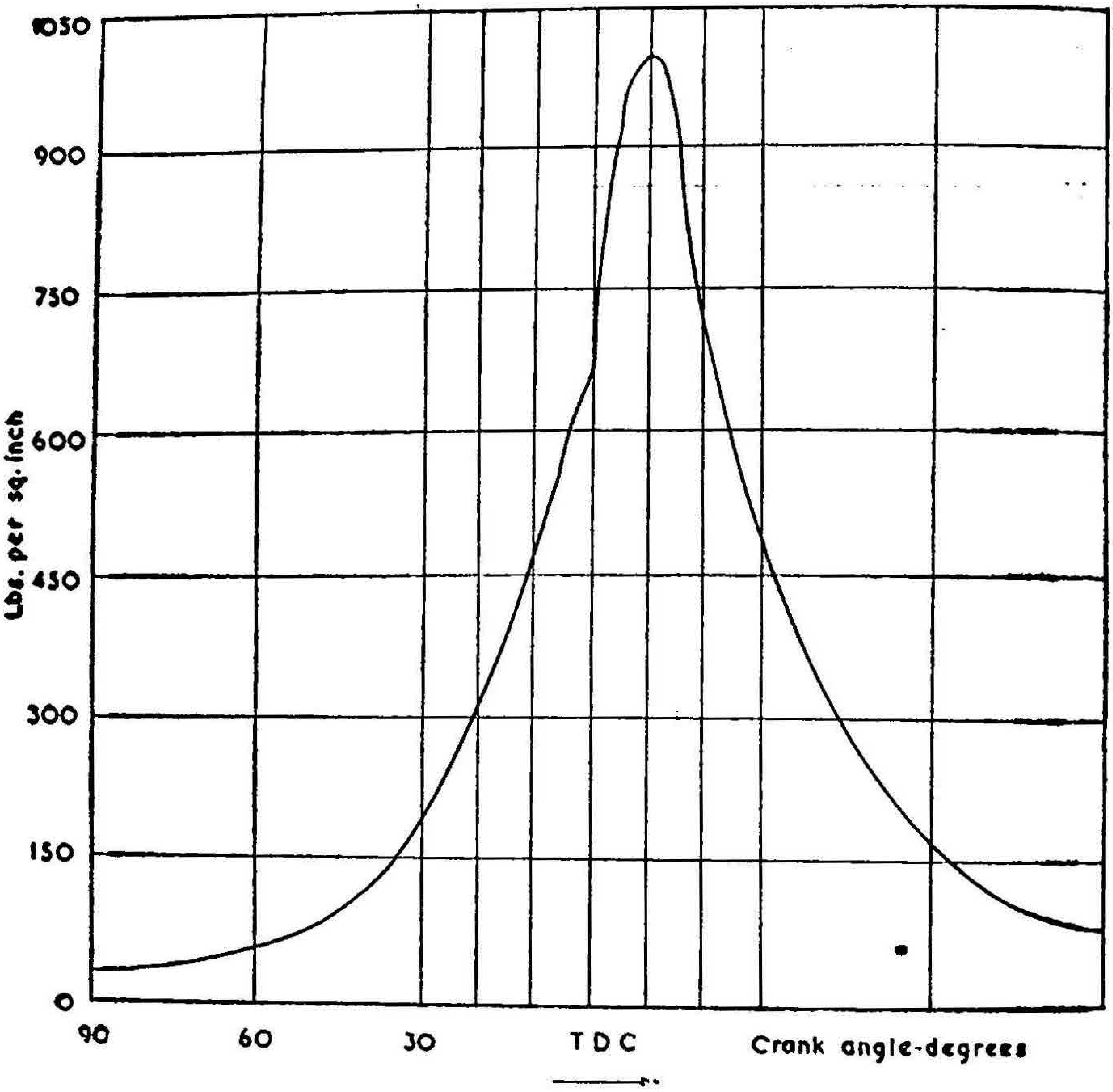


FIG. 6 *c*. Indicator Diagram
Ricardo E-6 Engine
Compression Ratio—21·22 : 1; Speed—1250 R.P.M.; Load—Full Load; Rate of Alcohol Carburetion—0·0120 Lb./Min.; Injected Fuel—Grade 'B' Oil
Angle of Advance of Injection—37° Before T.D.C.

engine, with an open combustion chamber. For this purpose, a Petter AV 1 series II engine developing 5 H.P., at 1500 R.P.M., was chosen. Detailed specifications of the engine are given in Table 2.

TABLE 2

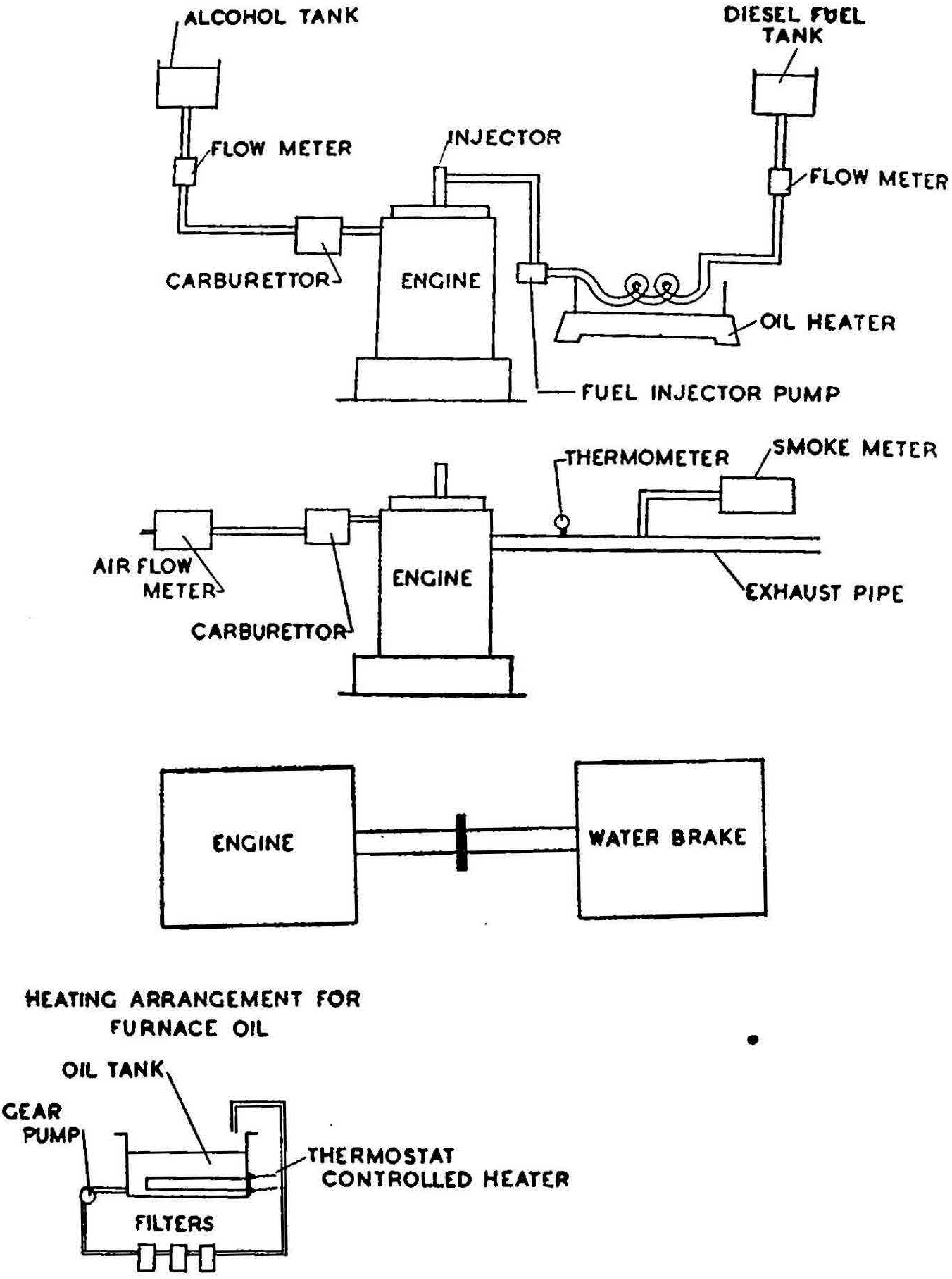
Specifications of Petter AV1 Series II Engine

General details	Four-stroke, compression ignition, vertical, cold starting, water cooled
Number of cylinders	1
Bore diameter	3·15 in. (80 mm.)
Stroke	4·33 in. (110 mm.)
Swept volume	33·73 cu. in. (553 c.c.)
Compression ratio	16·5: 1
Speed	1500 R.P.M.
Rated power	5 B.H.P.
Valve tappet clearance	0·007 in.
Inlet valve opens	4½° Before top dead centre
Inlet valve closes	35½° After bottom dead centre
Exhaust valve opens	35½° Before bottom dead centre
Exhaust valve closes	4½° After top dead centre
Fuel injection pressure	2,500 lbs. per sq. in.
Fuel injection timing	24° Before top dead centre
Nozzle	Three hole, 0·24 mm. dia. × 1·75 mm. long stem, No. HL—S 24 C 175 P 3.
Fuel pump	Bryce, type A1 AA 70/55. 99 No. AA 32967
Combustion chamber	Open combustion chamber
Fuel oil	A high grade light distillate Diesel fuel in accordance with B.S.S. No. 209/1947—Class A

5.21. *Test Set-up.*—The test set-up for this engine is indicated schematically by line diagram and shown in photographs in Figs. 7 *a*, 7 *b* and 7 *c*. The fuel control for this engine was by means of a centrifugal governor. This governor was retained. A three-way cock was fitted to the fuel inlet of the injection pump. With the help of this cock it was possible to change over easily from one type of fuel to another. Heavy fuel was preheated in a water-bath prior to its admission to the injection pump. This bath was located as close to the pump as practicable so that there was no chance for the fuel to congeal. A variable jet industrial carburettor was fitted to the inlet manifold and through this alcohol was inducted.

Flow meters were used to measure the consumption of the fuels, respectively.

Air flow was measured first with the help of an air box and later with an 'Alcock' flow meter to check up the results.



ENGINE SET UP FOR TESTING ALCOHOL AS SUPPLEMENTARY FUEL IN PETTER ENGINE

FIG. 7 *a*

Exhaust gas temperature was measured as close to the engine as possible. A C.R.C. Photoelectric smoke meter was used to estimate the smoke density. A rough estimate of the extent of carbon particles in the exhaust gas was made by collecting them on a glass plate and then photographing.

Power measurement was done by means of a water brake directly coupled to the engine.

Cooling water temperature was maintained at about 80° C. throughout the tests.

Fuels chosen for the tests were:

1. *B.S.S. Grade 'A' Diesel fuel.*—Fulfilling the makers specifications for use with the engine.
2. *B.S.S. Grade 'B' Diesel fuel.*—An inferior grade suitable for slow speed engines.
3. *Furnace oil.*—Used mostly in boiler practice.
4. *Power Alcohol.*—Power Alcohol produced by Mysore Sugar Factory, Mandya.

Detailed specifications of these fuels are given in Table 3.

TABLE 3

Properties of Diesel Oils, Furnace Oil and Alcohol Used in the Experiments

Type of fuel	Grade A oil	Grade B oil	Furnace oil	Alcohol
S.G. at 75° F.	0·84	0·87	0·90	0·78
Cetane number	45	40		
Viscosity at 100° F. Redwood I secs.	35	45	390	
Carbon residue Conradson, % weight	0·05	1·0	4·8	
Sulphur, % weight	0·3	1·2	2·5	
Water, % weight	nil	0·05	0·1	less than 0·5
Sediment, % weight	nil	0·01	0·01	
Ash, % weight	nil	0·01	0·01	
Calorific value, (Lower) B. Th. U/lb.	18,600	18,100	18,150	11,600

Fuels B.S.S. Grade 'A' and 'B' could flow freely at room temperature and they were supplied to the injection pump after filtration. Furnace oil was too viscous at room temperature to be acceptable to the injection equipment. It was therefore preheated to 90° C. and passed through three felt filters before it was transferred to the engine fuel tank. It was again heated in a water-bath to about 95° C. before it entered the injection pump. Specific gravity of this fuel at various temperatures was also determined experimentally and was used in the calculation of fuel consumption.

5.22. *Test Procedure.*—The engine was started and allowed to warm up on Diesel fuel for half an hour. It was then loaded to a predetermined value. Maintaining engine conditions steady the following observations were made.

(1) Speed of the engine, (2) Brake load, (3) Fuel consumption, (4) Air consumption, (5) Ambient air temperatures and pressure and humidity, (6) Exhaust gas temperature, (7) Smoke density, (8) Collection of carbon particles in exhaust gas on a glass plate for 15 seconds and photographing.

Maintaining the brake load at this value, alcohol was admitted by stages into the engine while the fuel pump governor automatically reduced proportionately the fuel oil injected. As the percentage of alcohol inducted increased a stage was reached when the engine started missing and hunting. This was the maximum limit for the admission of alcohol. For each combination of alcohol and Diesel fuel proportions one set of observations was recorded as before, the only additional observation being the alcohol flow meter reading. This procedure was repeated for ½, ¾, full and overload conditions. The '*full load neat fuel smoke density*' was the limit up to which the engine was overloaded for each fuel.

5.23. *Test Results.*—The test results are graphically presented in Figs. 8 *a*, 8 *b*, 8 *c*, 8 *d*, 8 *e*, 8 *f*, 8 *g*-1 and 8 *g*-2, and summarised below:

1. Under full load conditions nearly 70% of alcohol could be inducted in combination with Grade ' A ' fuel. On the other hand, under the same load conditions, only 60% of alcohol could be inducted in combination with either Grade ' B ' fuel or furnace oil. Under overload conditions slightly lower percentages of alcohol could be inducted (Fig. 8 *a*).

2. The engine could be overloaded to about 45% and 40% with Grade 'A' and Grade 'B' fuels respectively with alcohol induction. Under overload conditions the smoke density *was no more than that at full load with neat Diesel fuel.* When running on neat furnace oil, however, it was found that the engine could be loaded only to 50% for passable smoke density. With the addition of alcohol it was possible to load the engine to the full value for passable smoke density (Fig. 8 *b*).

3. A direct inference from result (2) was that the air utilization factor was higher with alcohol induction, as compared to normal running conditions,

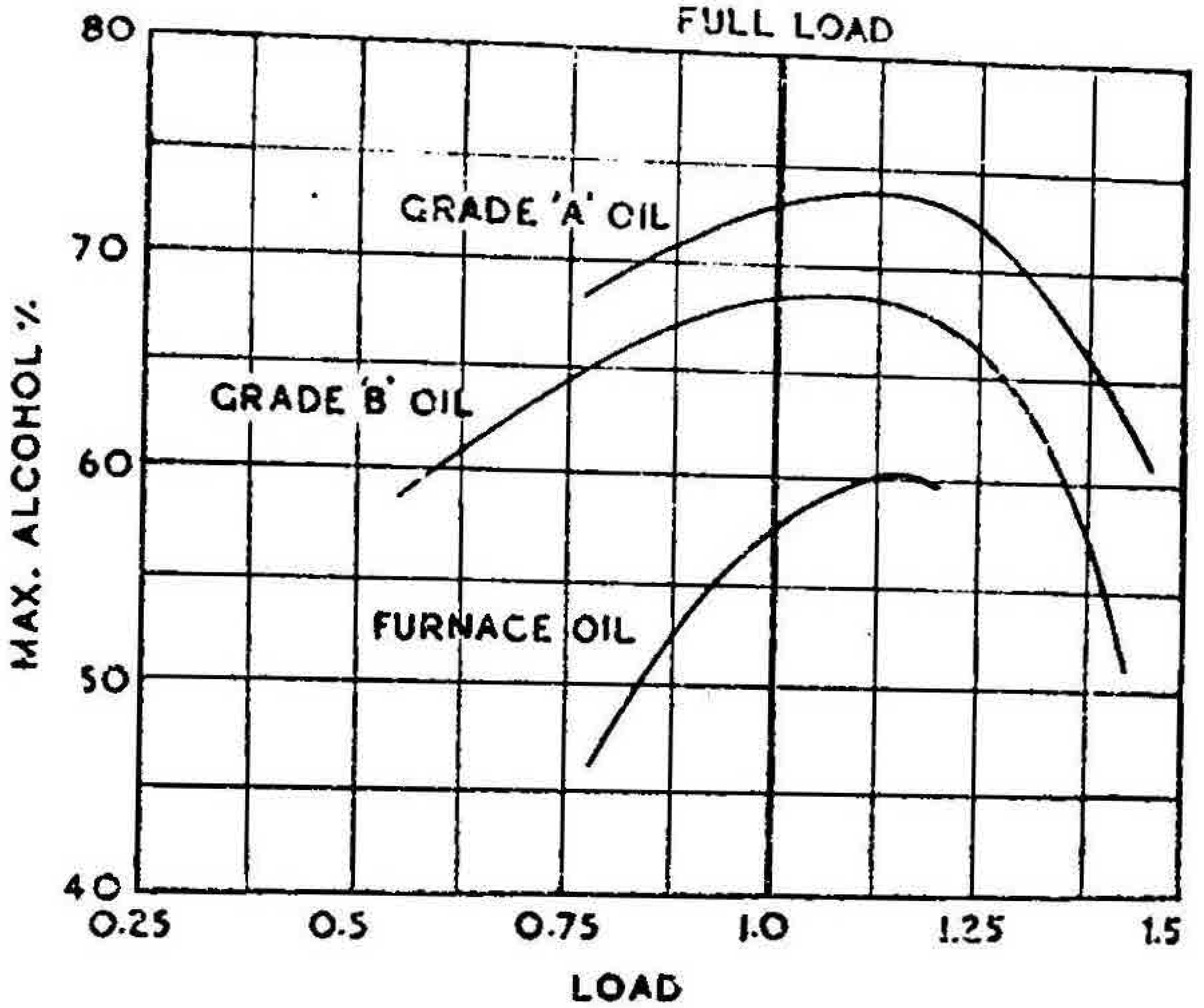


Fig. 8 *a*

Petter Engine

Compression Ratio—16·5 : 1; Speed—1500 R.P.M.; Angle of Advance of Injection—27° Before T.D.C.

4. At full and part load conditions there was generally a drop in the thermal efficiency of the engine when run on any of the Diesel fuels in combination with alcohol carburetion. Under overload conditions there was a definite improvement in thermal efficiency (Figs. 8 *c* and 8 *d*).

5. There was a slight improvement in the volumetric efficiency.

6. The smoke density was reduced considerably as a result of induction of alcohol. For any particular load, the higher the rate of alcohol inducted, the lower was the smoke density. When the engine was run on Grade 'A' and Grade 'B' fuels at full load with induction of maximum quantity of alcohol the exhaust colour was comparable to that of a petrol engine (Fig. 8 *e*).

7. Exhaust temperature generally increased slightly with the induction of alcohol except in the case of furnace oil where it decreased slightly at higher loads (Fig. 8 *f*).

8. Proportion of free carbon particles in the exhaust gas was lower with alcohol induction. This was very pronounced in the case of furnace oil (Figs. 8 *g*-1 and 8 *g*-2).

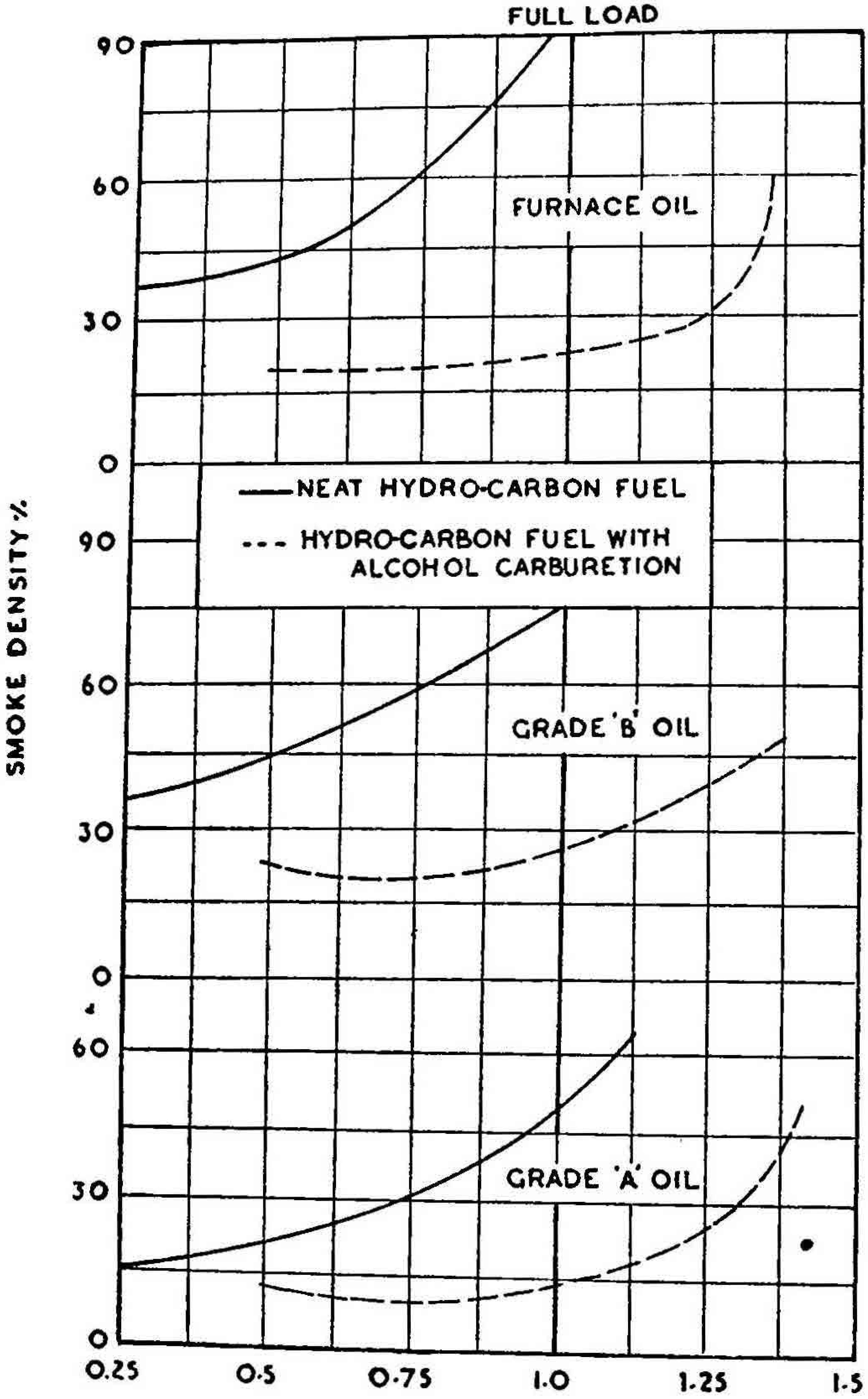


FIG. 8 *b*

Petter Engine

Compression Ratio—16·5 : 1; Speed—1500 R.P.M.; Angle of Advance of Injection—27° Before T.D.C.

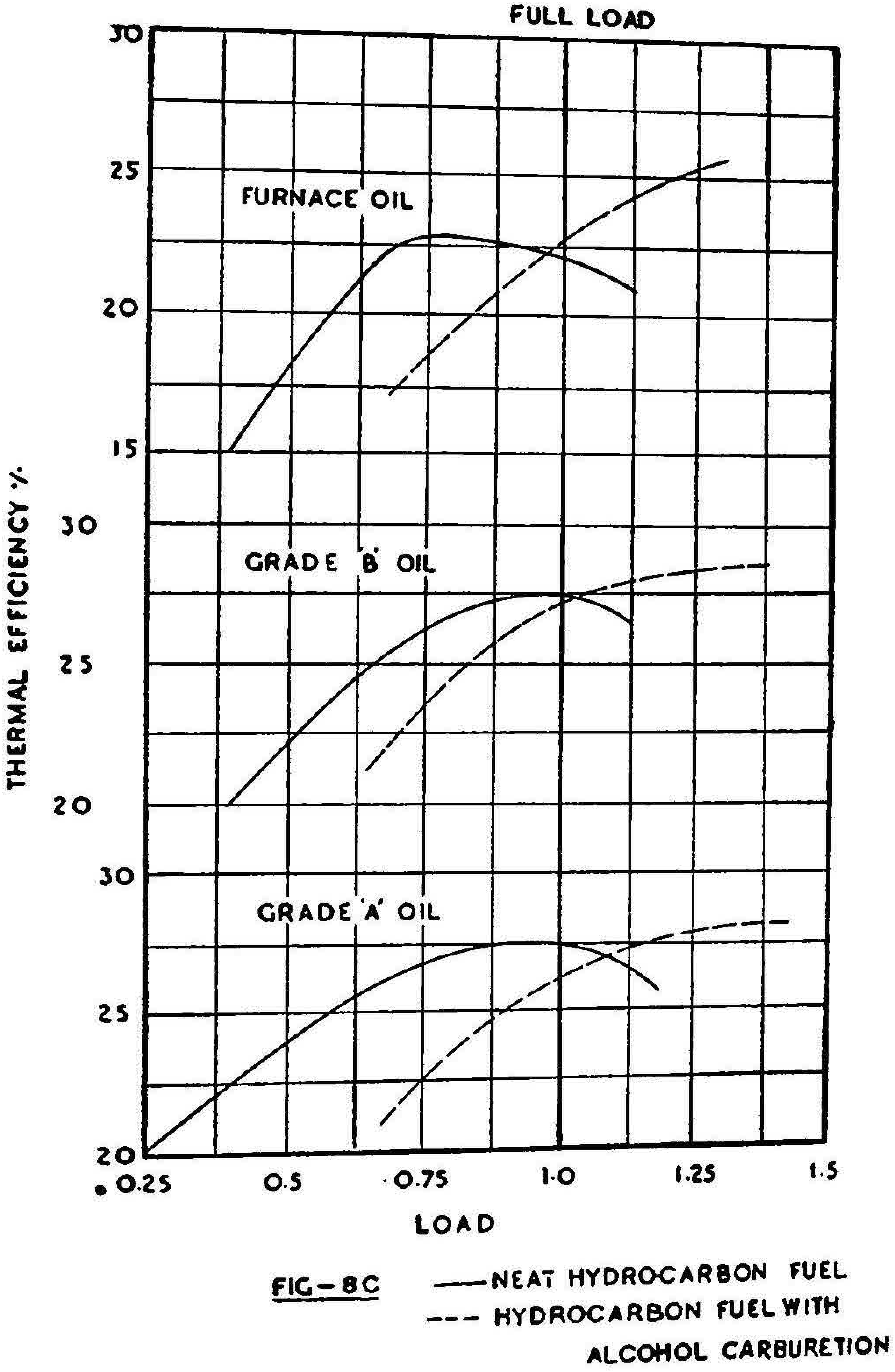
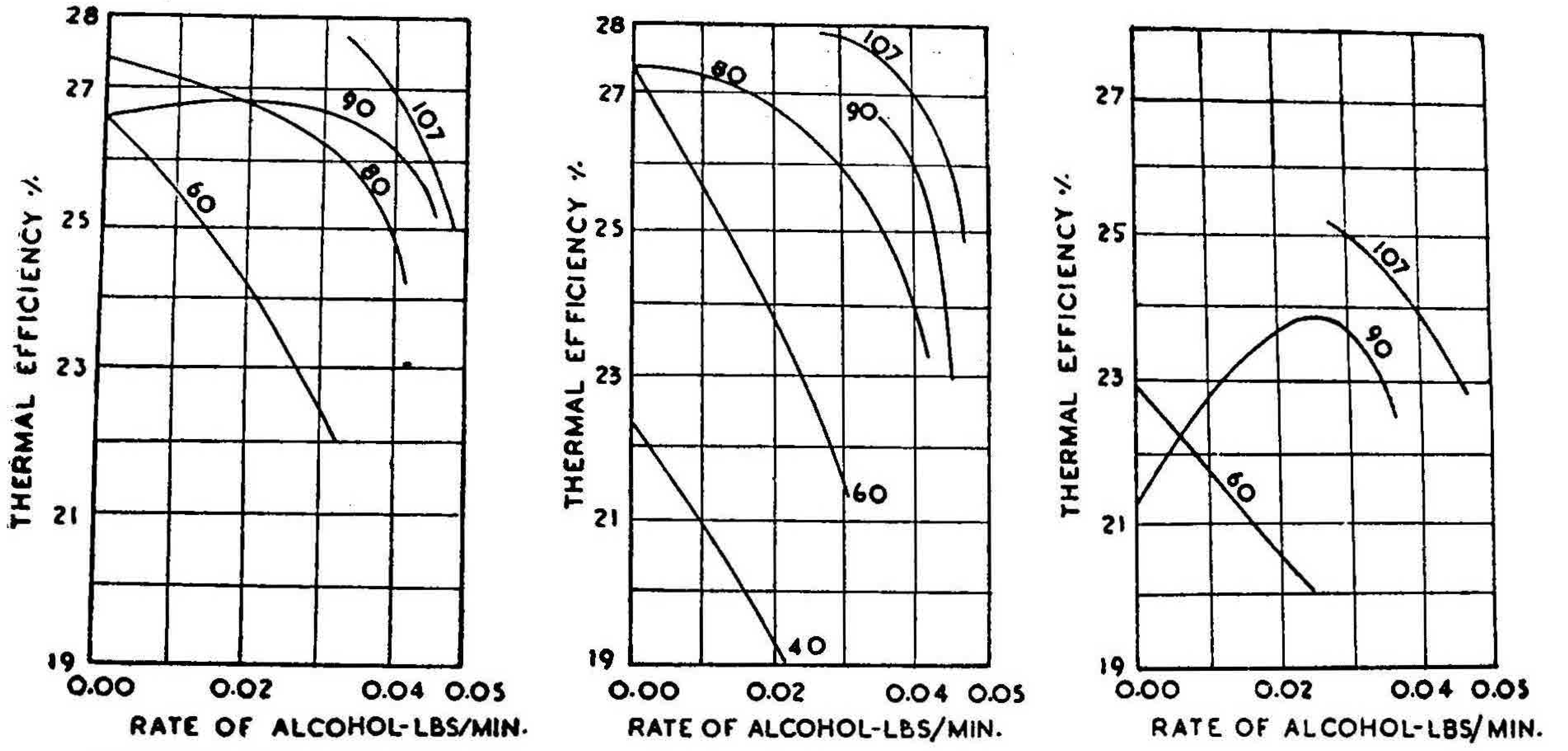


FIG. 8 *c*

Petter Engine

Compression Ratio—16·5: 1; Speed—1500 R.P.M.; Angle of Advance of Injection—27° Before T.D.C.



INJECTED FUEL-GRADE 'A' OIL

INJECTED FUEL-GRADE 'B' OIL

INJECTED FUEL-FURNACE OIL

FIG. 8 *d*

Petter Engine

Compression Ratio—16·5 : 1; Speed—1500 R.P.M.; Angle of Advance of Injection—27° Before T.D.C.; 80 Lb./Sq. Inch. B.M.E.P.—Full Load

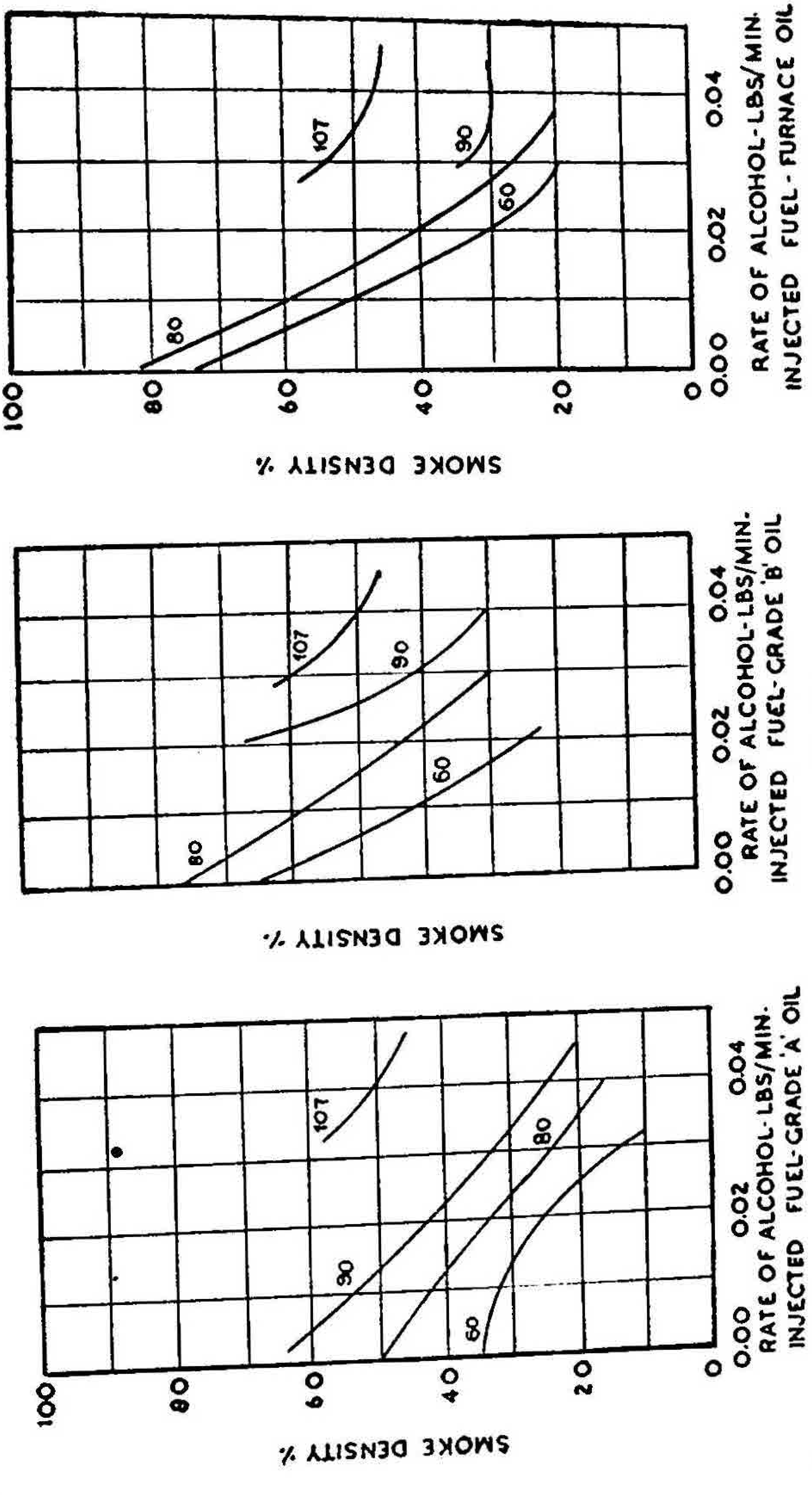


FIG. 8 *e*

Petter Engine

Compression Ratio—16·5 : 1; Speed—1500 R.P.M.; Angle of Advance of Injection—27° Before T.D.C.; 80 Lb./Sq. Inch. B.M.E.P.—Full Load

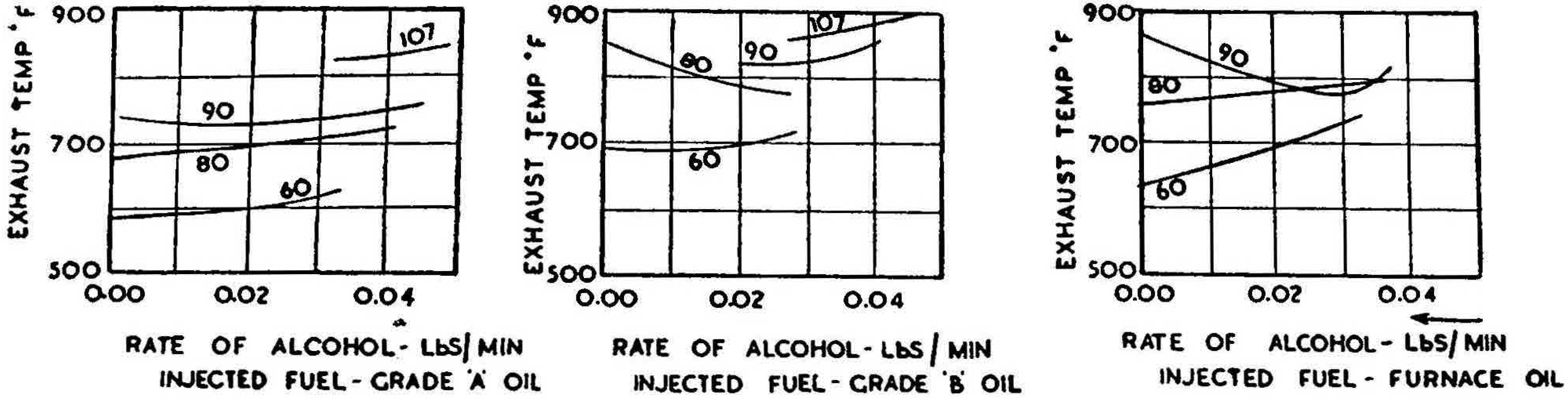


FIG. 8 *f*

Petter Engine

Compression Ratio—16·5 : 1; Speed—1500 R.P.M.; Angle of Advance of Injection—27° Before T.D.C.; B.M.E.P.—80 Lb/Sq. Inch at Full Load

5.24. *Alcohol Water Solution as Supplementary Fuel.*—A second set of experiments was conducted subsequently to study the influence of water dissolved in alcohol, on the performance of the engine. For this purpose, solutions of water and alcohol were prepared in different proportions and tried in combination with Grade 'B' oil in the above test set-up. The observations are given in Appendix II. The results can be summarised as follows:

1. Up to 30% of water could be mixed with alcohol without any deterioration in performance of the engine.
2. There was not much variation in thermal efficiency.
3. There was little difference in the exhaust temperature. But the trend was generally towards lower values as compared to pure alcohol.
4. There was no perceptible variation in smoke density.

6. DISCUSSION OF RESULTS

Two engines have been chosen for the experiments enumerated above, *i.e.*, (1) the Ricardo E-6 Engine which is a precombustion chamber engine with a compression ratio of 21·22: 1 and (2) the Petter Engine, which is an open combustion chamber engine with a compression ratio of only 16·5 : 1.

The Ricardo engine is much less sensitive towards the grade of fuel supplied, while the Petter engine is intended to run on those fuels that come within B.S.S. 209–1947-Class A.

6.1. *Combustion Characteristics.*—In the case of the Ricardo engine, the maximum amount of alcohol that can be carburetted into the engine is limited by the occurrence of knocking in the engine, whereas in the case of Petter engine, it is limited by missing and hunting. Under no condition of running, with alcohol, is knocking detected in the case of the Petter engine.

It has been noticed that as long as the air-alcohol ratio is greater than 54: 1, whatever the load condition, there will be no knocking in the Ricardo engine. As soon as the mixture is made richer, knocking starts. This may be, perhaps, due to the fact that enrichment of the mixture brings down the spontaneous ignition temperature and leads to auto-ignition of the mixture, specially, where the compression ratio and hence, the compression temperature are high. On the other hand, in the case of Petter engine, the compression ratio and hence, the compression temperature are comparatively of a lower value; because of this fact, however much the mixture is enriched, there is no possibility of self-ignition and consequent knocking. This is further substantiated by the fact that the Petter engine began to knock violently, when 73 octane petrol having a lower self-ignition temperature than alcohol was inducted into the engine.

From these considerations, it may be concluded that the main condition to be satisfied by an inducted fuel is that it must have a high self-ignition temperature.

It is also to be noted that in the Petter engine, enriching the mixture beyond the maximum limit causes missing and hunting under all load conditions. The cause for this is not clear and is a matter for further investigation.

It is seen from the curves in Fig. 9 that for any particular air-alcohol-ratio the quantity of Diesel fuel injected per cycle will be a minimum with Grade 'A' fuel and a maximum with furnace oil. This indirectly indicates that in combination with Grade 'A' fuel a maximum amount of alcohol can be utilised in the engine and this quantity is reduced as the fuel becomes heavier.

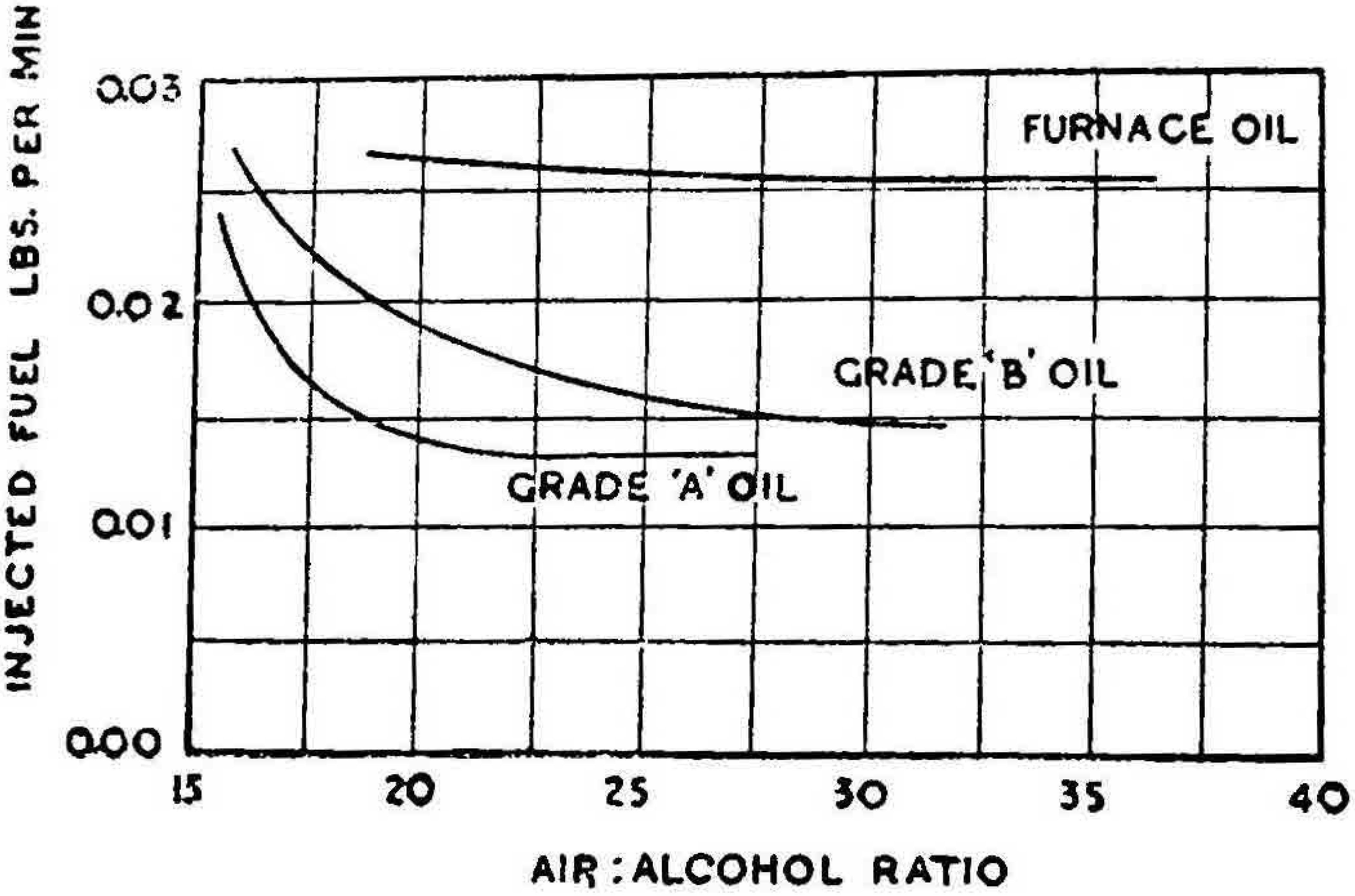


FIG. 9

Petter Engine

Compression Ratio—16·5 : 1; Speed—1500 R.P.M.; Angle of Advance of Injection—27° Before T.D.C.

6.2. *Overload.*—The Diesel engine, when run on carburetted alcohol with any of the three hydrocarbon fuels, gives a higher air utilization factor. Consequently, the engine can be overloaded to nearly 40–45% in the case of Grade 'A' oil and 35–40% in the case of Grade 'B' oil. It is to be noted that the higher the amount of alcohol carburetted, the higher is the overload that the engine can take.

6.3. *Thermal Efficiency.*—In the case of the Ricardo engine, running on Grade 'B' oil and with alcohol induction, there is a certain, though small, increase in the thermal efficiency of the engine. Figures 6 *a*, 6 *b* and 6 *c* show the indicator diagrams taken at full load, on the Ricardo engine with Grade 'B' oil alone and Grade 'B' oil and alcohol inducted at the rate of 0·01 lb. per minute and 0·012 lb. per minute respectively. With alcohol carburetted into the engine the pressure crank angle curve becomes steeper; hence the greater the amount of alcohol carburetted, the steeper the curve. The combustion tends to be completed earlier and the peak pressure is reached earlier in the cycle, and hence the increase in thermal efficiency of the engine. This may also account for the incidence of knocking, with higher rates of alcohol induction than 0·012 lb. per minute.

In the case of the Petter engine, it is seen that the thermal efficiency of the engine generally decreases slightly with the induction of alcohol into the engine. But, at overloads a higher thermal efficiency is recorded. The exact cause for the drop in the thermal efficiency at part loads is not clear.

6.4. *Volumetric Efficiency.*—There has been no appreciable difference in the volumetric efficiency of the engine due to the induction of alcohol.

6.5. *Smoke Density.*—It is seen from Figs. 5 *a*, 5 *c* and 8 *e*, that for the same load, the smoke density is always reduced with the induction of alcohol. This appears to be due to (1) a smaller quantity of hydrocarbon fuel burnt per cycle, (2) all the fuel being injected during the early part of the cycle and (3) the rapid combustion of alcohol leading to higher turbulence, all of which are conducive to better combustion of the hydrocarbon fuels. The quantity of hydrocarbon fuel burnt per cycle in the engine increases at overload and the smoke density also increases proportionately.

6.6. *Free Carbon Particles.*—The presence of free carbon particles in the exhaust is reduced considerably with the induction of alcohol. The combustion of injected fuel is predominantly one of oxidation of products of destructive decomposition. In this case, there are greater chances of the fuel cracking and forming carbon particles. On the other hand, the combustion of alcohol is predominantly a process of hydroxilation and the chances of the fuel cracking are negligible. Consequently, induction of alcohol reduces the quantity of carbon particles in the exhaust gases. This fact is illustrated clearly in Figs. 8*g*-1 and 8 *g*-2. Fig. 8 *g*-1 is the photograph of the carbon particles collected from the exhaust of the Petter engine running on furnace oil and Fig. 8 *g*-2 is a similar photograph taken when the engine was running on furnace oil and alcohol. The corresponding smoke densities are 90% and 30% respectively.

6.7. *Water Tolerance.*—As mentioned elsewhere, the principal drawback of alcohol-Diesel fuel blends is its low water tolerance. Carburetion of alcohol successfully overcomes this drawback. As much as 30% of water in solution with alcohol does not seem to have any adverse effect on the performance of the engine. Thus, even though alcohol may contain accidentally large quantities of water, still, it can be inducted. Furthermore, with this method, one need not insist on anhydrous alcohol. The usual 95% alcohol that can be produced easily can serve for the purpose of induction into high speed Diesel engine.

7. CONCLUSIONS

1. Alcohol can be used as a power booster fuel in a high compression precombustion-chamber engine. It can be used as a primary fuel, in the case of open combustion chamber high speed diesel engines, both for normal running and high power boost.

2. Under overload conditions, higher air utilization is obtained.

3. For periodic boosting of transport or marine high speed Diesel engines this promises to be a better, cheaper and simpler alternative to supercharging.

4. Induction of alcohol invariably results in a cleaner exhaust, especially at higher power output.

5. The exhaust temperature with alcohol is higher in the case of Grade 'A' and Grade 'B' oils and lower with furnace oil.

6. The presence of large proportions of water in the alcohol does not affect the performance of the engine and so it is not necessary to have anhydrous alcohol for this purpose.

8. FUTURE WORK

1. The effect of the carburetion of alcohol and alcohol-water solution on the wear and corrosion of engine components requires further investigation.

2. The influence of different engine variables like speed, compression ratio, type of combustion chamber, etc., on the most suitable proportion of alcohol needs to be studied.

3. Application of this method should be extended to multicylinder engines—supercharged and unsupercharged.

4. Fundamental study of the combustion process involved in alcohol-hydrocarbon fuel combination has to be undertaken.

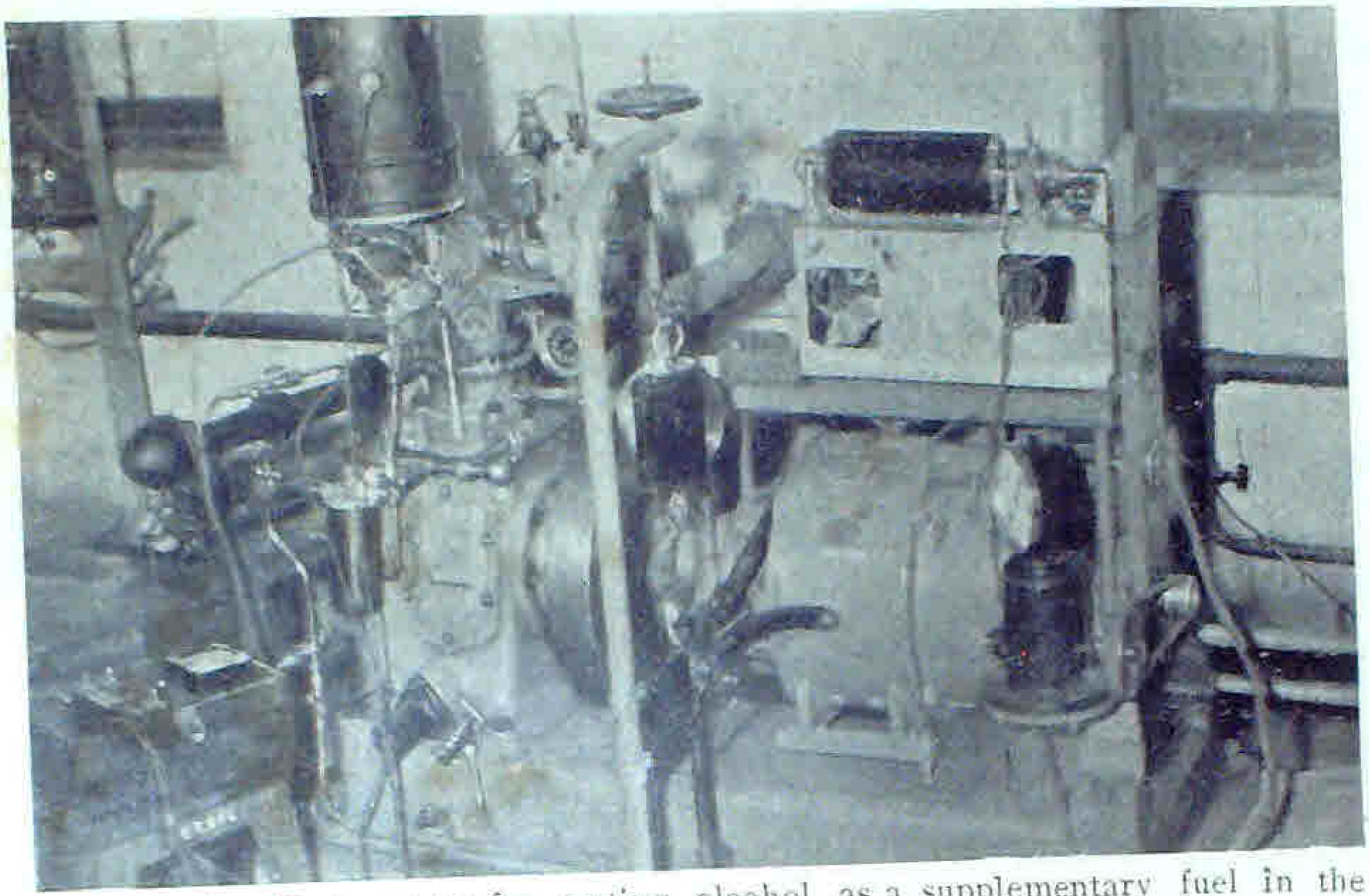


FIG. 4-b. Test set-up for testing alcohol as a supplementary fuel in the Ricardo E-6 engine

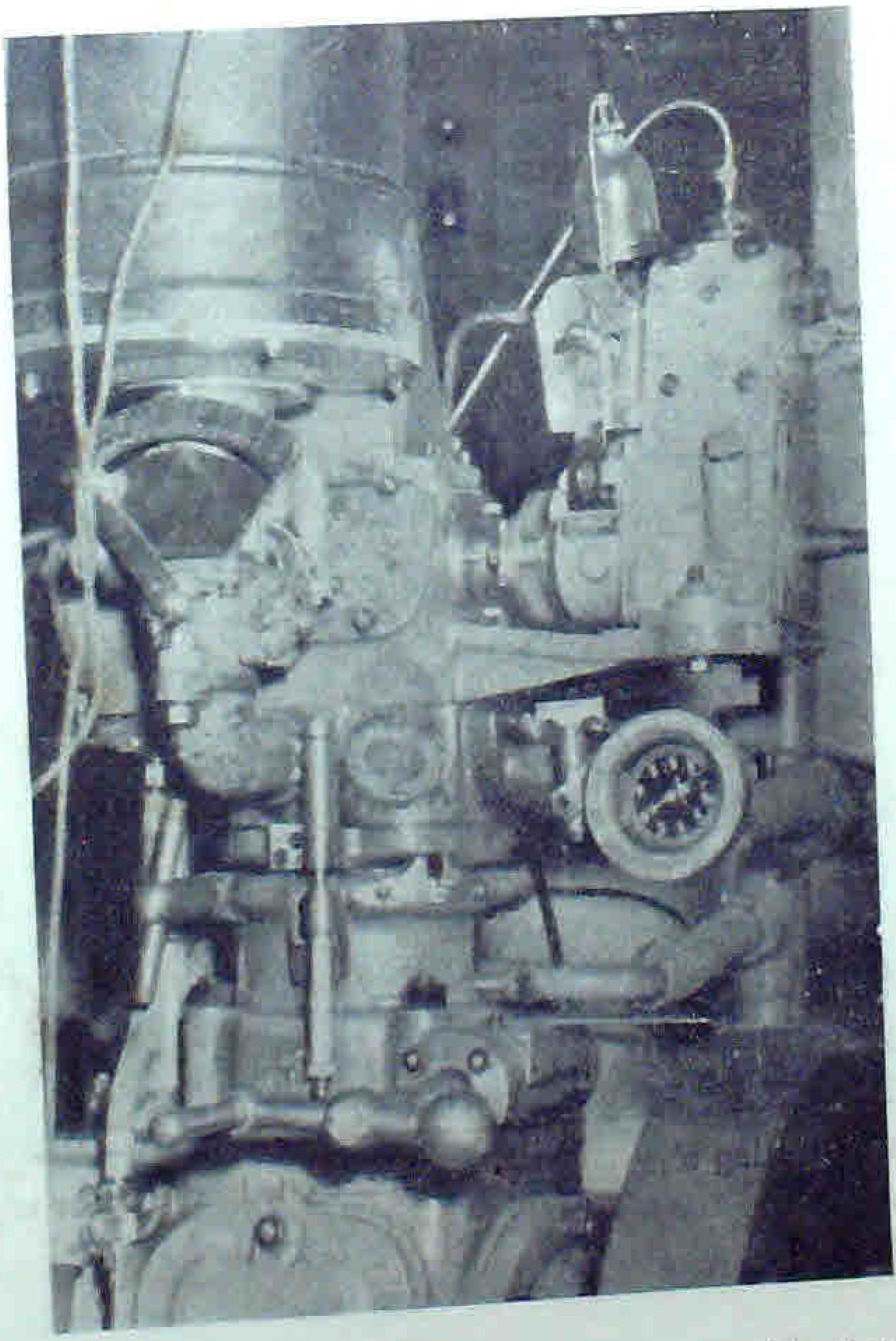


FIG. 4-c. Close-up view of the carburettor and injector combination in the Ricardo engine test set-up

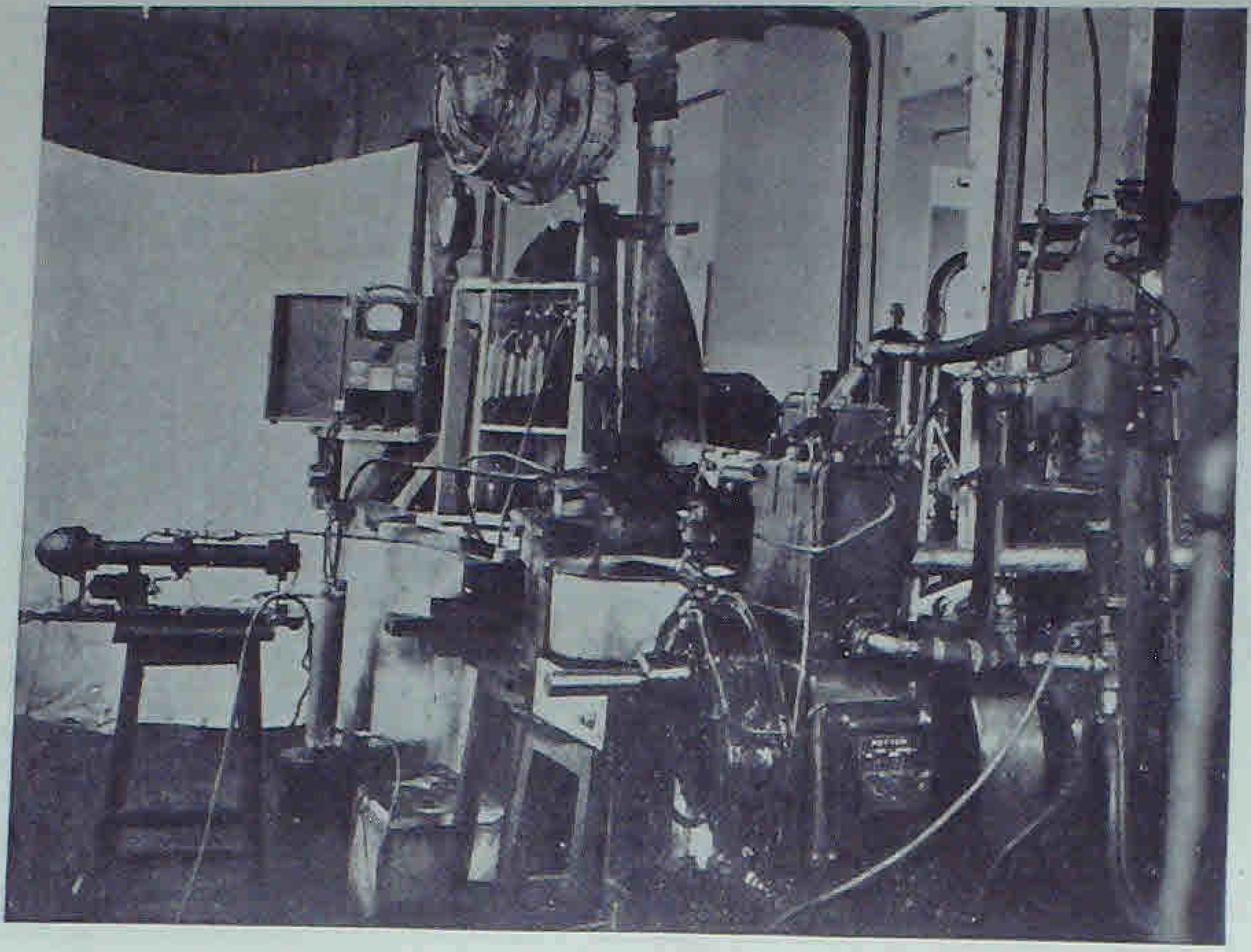


FIG. 7-b. Test set-up for testing alcohol as a supplementary fuel in the Petter engine

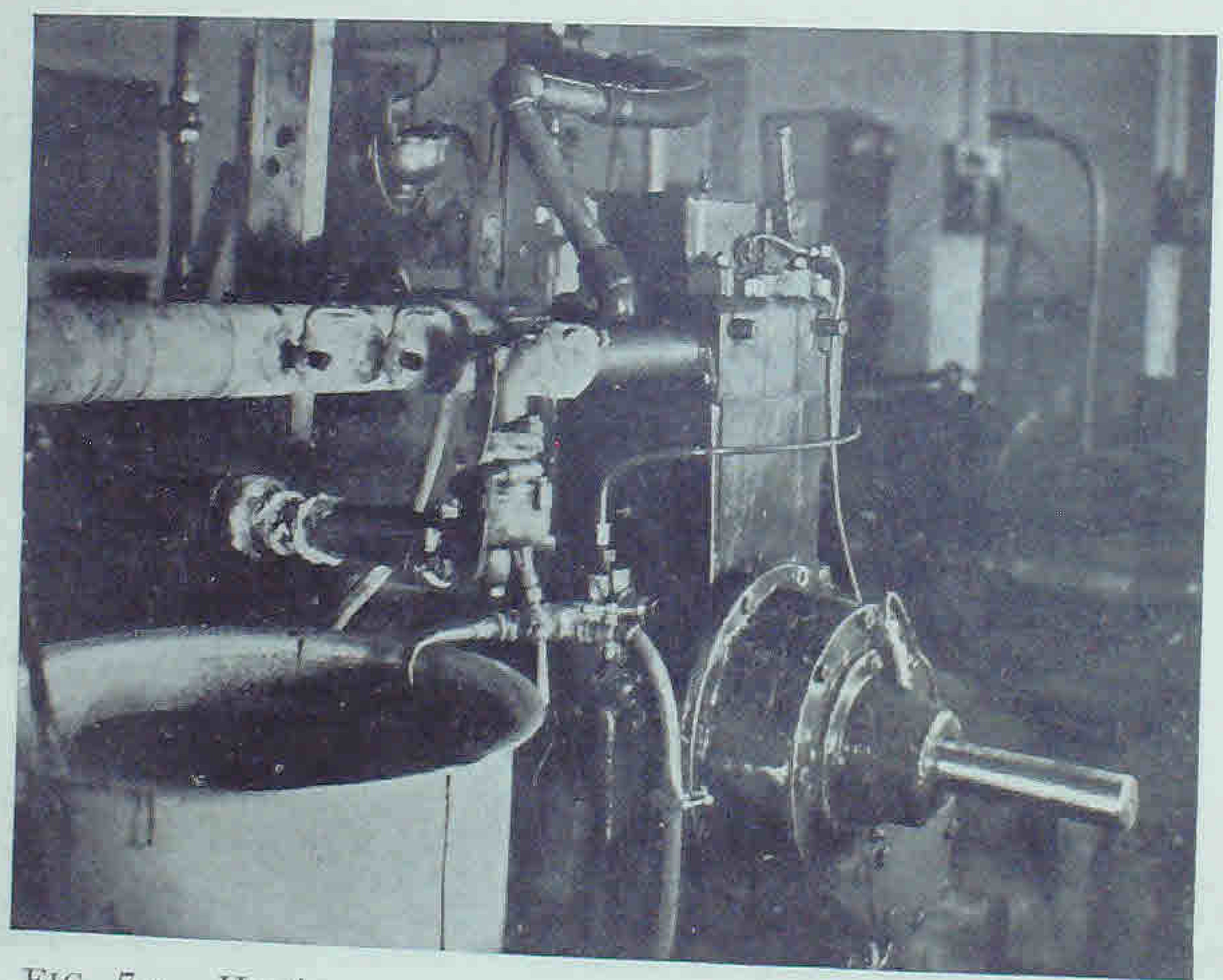


FIG. 7-c. Heating arrangement for furnace oil, in the Petter engine set-up

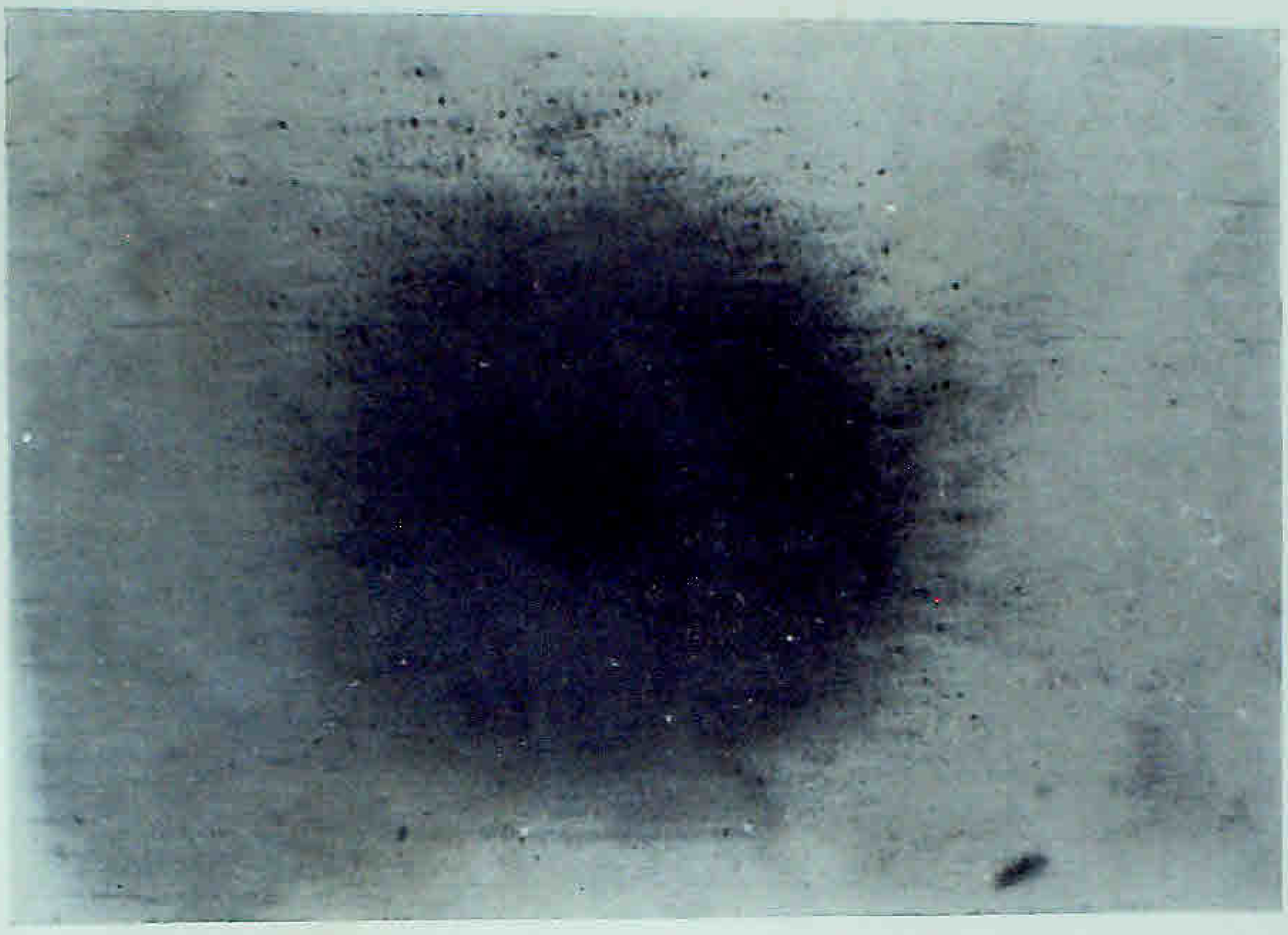


FIG. 8g-1. Carbon particles in the Exhaust of Petter engine running on furnace oil at full load, collected on a glass plate, held into the exhaust stream for 15 seconds.

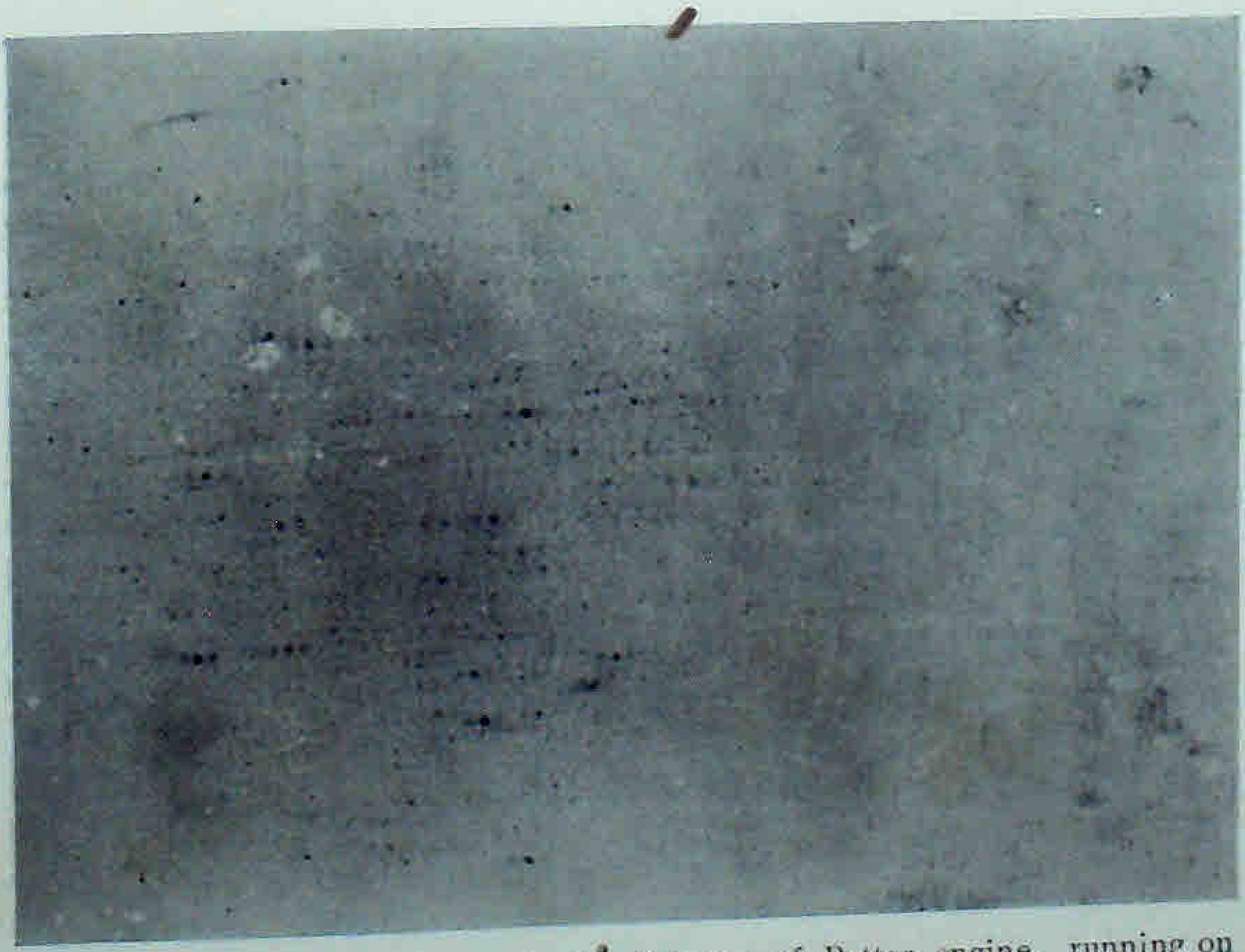


FIG. 8g-2. Carbon particles in the Exhaust of Petter engine, running on furnace oil, with alcohol carburetion, at full load, collected on a glass plate, held into the exhaust stream for 15 seconds.

5. The causes for lower thermal efficiency and the missing and hunting when an excessive proportion of alcohol is inducted into the Petter engine or similar types need further investigation.

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APPENDIX I

Results of Experiments Regarding Miscibility of Diesel Fuels with Alcohol

Grade 'A' Oil and Alcohol

Grade 'A' oil c.c.	Alcohol c.c.	Room Temperature	Heated to 60° C.	Few Drops Water Added
20	5	4·5 c.c. alcohol separated	Clear solution	Separation takes place
20	10	11 c.c. Grade 'A' oil separated	,,	,,
20	15	16 c.c. Grade 'A' oil separated	,,	,,
20	20	14 c.c. Grade 'A' oil separated	,,	,,
5	20	1 c.c. Grade 'A' oil separated	,,	,,
10	20	4 c.c. Grade 'A' oil separated	,,	,,
15	20	14 c.c. Grade 'A' oil separated	,,	,,

Grade 'B' Oil and Alcohol

Grade 'B' oil c.c.	Alcohol c.c.	Room Temperature	Heated to 60° C.	Few Drops Water Added
20	5	4·5 c.c. alcohol separated	1·5 c.c. alcohol separated	Separation takes place
20	10	8 c.c. alcohol separated	Clear solution	,,
20	15	12 c.c. alcohol separated	7 c.c. Grade 'B' oil separated	,,
20	20	13 c.c. alcohol separated	9 c.c. Grade 'B' oil separated	,,
5	20	Turbid solution	Turbid solution	..
10	20	,,	,,	..
15	20	,,	,,	..

Furance Oil and Alcohol

There was no miscibility either at room temperature or elevated temperatures.

APPENDIX II

Observations of Tests with Alcohol-Water Solution as a Supplementary Fuel in the Petter Engine

Load: Full load Injected fuel: Grade 'B' oil

Per cent. of water in alcohol	Exhaust Temperature	Smoke density per cent.	Thermal efficiency	Per cent. of alcohol
0	720° F.	10	25	64
5	720° F.	10	23·9	60
10	680° F.	10	25	62
15	700° F.	15	25·5	60·5
20	710° F.	28	25·6	58·5
25	680° F.	30	26·2	54·5
30	690° F.	15	25·5	55