ALCOHOL IN DIESEL ENGINES*

The Utilization of Power Alcohol in Combination With Normal and Heavy Fuels in High Speed Diesel Engines

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THE development of a method of using Power Alcohol in combination with cheaper, low grade fuels is interesting from a technical point of view, since it makes practicable the employment of heavier fuels in high speed diesel engines. It is also interesting because, in some countries, Power Alcohol is available in considerable quantities as an indigenous fuel, for which the opening of an additional market may be a progressive step economically.

This investigation was therefore carried out to determine the advantages and disadvantages of using alcohol in some engines of common design having a high compression ratio and accepting alcohol in proportions much greater than are employed at present. It was also aimed at overcoming the limitations set by the poor water tolerance of blends of alcohol with most hydrocarbon fuels. Another problem that 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 are cheaper than the oils for high speed units.

However, heavy fuels have two main disadvantages, and these make them unsuitable for use in high speed diesel engines: they are the slowness of the combustion process, which results in a smoky exhaust, and the high sulphur content, which leads to excessive corrosive wear. It was therefore decided that if a method were discovered that made possible the use of these fuels in high speed diesel engines, it would constitute a step forward economically and scientifically.

Review of previous work

Much 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 headings:

1. Improving the ignition quality of the fuel.
2. Minimizing the deleterious effects of high sulphur and carbon residues.

Ignition quality of the fuel: Regarding the ignition quality of the fuel, Ricardo[1] has shown 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 octane value. One of the practical objections to these accelerators is their high cost. Another is their effect on engine life, but little is known about this aspect. As the proportion of additive is increased, the accelerating effect of each increment decreases.

A second line of attack on the problem of improving combustion is by supercharging the engine. In a recent address, Ricardo[2] has given particulars of tests that he had carried out on an engine running at 1,500-2,000 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 be a good remedy but it will also increase the cost of the basic engine unit as well as the cost of maintenance. The air utilization factor, however, apparently does not vary a great deal.

McLaughlin[3] and his associates report that combustion in a high speed diesel engine could be accelerated by carburetting volatile fuel of a high self-ignition temperature. Advantage can be taken of this phenomenon either to reduce the exhaust smoke density or, for the same smoke density, to boost the engine power by some 20 per cent. Maxwell, of the Caterpillar Corporation, found that by carburetting mixtures of alcohol and water in a supercharged diesel engine, the efficiency could be slightly improved, as also could the power output.

Young, of the Sinclair Research Laboratories, found that fuels requiring a compression ratio of 25:1 for correct combustion could be made to burn satisfactorily at a compression ratio of 12:1 by carburetting some 5 per cent of *n*-Heptane. By a similar method, the authors have found it possible to use distillate fuels with a cetane value as low as 12, and the performance is as good as that of diesel fuels having a cetane value of 50. H. M. Gadebusch, of General Motors, has also reported similar results. Hobbs[4] 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, when using diesel oil and ethanol in a dual injection engine, obtained similar results.

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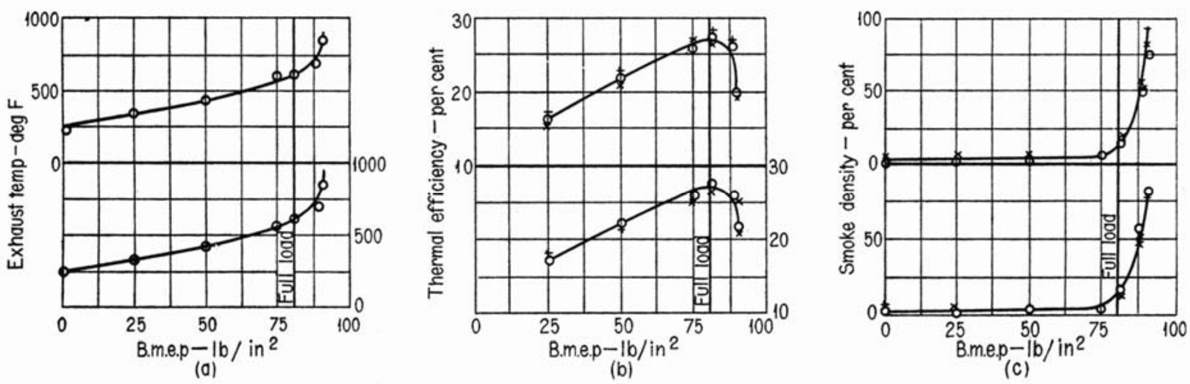

Fig. 1. Ricardo E6 engine: compression ratio: 21·22: 1. Speed 1,250 r.p.m. Fuels: Grade A and Grade B oils, and blends of these oils with alcohol. Injection timing: 37 deg B.T.D.C. The lower curves in a, b and c were obtained with Grade A oil and blends, and the upper ones with Grade B oil and blends

+ neat fuel × with 5 per cent blend o with 10 per cent blend

Utilization of power alcohol in high speed diesel engines

Deleterious effects of residual matter: With regard to the deleterious effects of high sulphur and carbon contents in heavy fuels, Brewer and Thorp[5] have shown that, for medium speed engines, the use of heavier fuels leads to injector nozzle encrustation, and cylinder wear and crankcase fouling are slightly increased. J. P. R. Smith[6] has also noticed similar effects when medium speed engines are run on heavy fuels. In large, slow speed engines, Lamb[7] reports that there is little or no increase in the rate of liner wear or carbon deposit resulting from a change to residual fuel. On the other hand, in a high speed engine developing 5 b.h.p. at 1,500 r.p.m., A. Natarajan and M. R. K. Rao[8] have found 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.

Broeze and Wilson[9] report that sulphur in the fuel aggravates the liner wear problem. C. H. Cloud and A. J. Blackwood,[10] of Esso Laboratories, have obtained the same results. It is suggested that the sulphur in diesel fuel burns to sulphur trioxide, which raises the dew point and causes condensation of aqueous acid products at a higher temperature than is normally expected. This leads to increased liner wear and sludge formation. A reduction in the rate of wear can be obtained by chromium plating liners or piston rings and by using heavy duty additive type lubricants.

Conclusions from previous work: The foregoing review can be summarized thus:

1. It has been found in practice that heavier fuels, provided they are preheated and purified, can be burned successfully in large and medium size engines without the addition of ignition accelerators. However, in the case of high speed engines it is necessary that some sort of combustion accelerator should be employed in addition to preheating and purifying the fuel.
2. Because of economic and other considerations, chemical accelerators have not yet become a practical success.
3. Carburation of suitable quantities of volatile fuels of 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 improvements in combustion and engine performance.
5. Heavier fuels lead to higher rates of carbon deposit and wear, but combustion accelerators may reduce these defects.
6. Chromium plating liners or top rings and the use of heavy duty lubricants reduce cylinder wear.

TABLE 1. RESULTS OF EXPERIMENTS REGARDING MISCIBILITY OF DIESEL FUELS WITH ALCOHOL

(With furnace oil and alcohol there was no miscibility either at room temperature or elevated temperatures)

Oil cm^3	Alcohol cm^3	Room Temperature	Heated to 60 deg C	Few Drops Water Added
Grade A				
20	5	4·5 cm^3 alcohol separated	Clear solution	Separation takes place
20	10	11 cm^3 Grade A oil separated	,,	,,
20	15	16 cm^3 Grade A oil separated	,,	,,
20	20	14 cm^3 Grade A oil separated	,,	,,
5	20	1 cm^3 Grade A oil separated	,,	,,
10	20	4 cm^3 Grade A oil separated	,,	,,
15	20	14 cm^3 Grade A oil separated	,,	,,
Grade B				
20	5	4·5 cm^3 alcohol separated	1·5 cm^3 alcohol separated	Separation takes place
20	10	8 cm^3 alcohol separated	Clear solution	,,
20	15	12 cm^3 alcohol separated	7 cm^3 Grade B oil separated	,,
20	20	13 cm^3 alcohol separated	9 cm^3 Grade B oil separated	,,
5	20	Turbid solution	Turbid solution	
10	20	,,	,,	
15	20	,,	,,	

Scope of the work presented

The foregoing review shows 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 successfully as a combustion accelerator. While Hobbs used a blend of alcohol and diesel fuel in an ordinary engine, Aubert applied a dual injection system and the others used carburettors, etc., for introducing volatile fuels mostly for the purpose of boosting the power output. Consequently, only a low percentage of volatile fuel was introduced. The aim of the investigation described here was, however, to find a way of using alcohol as the principal fuel.

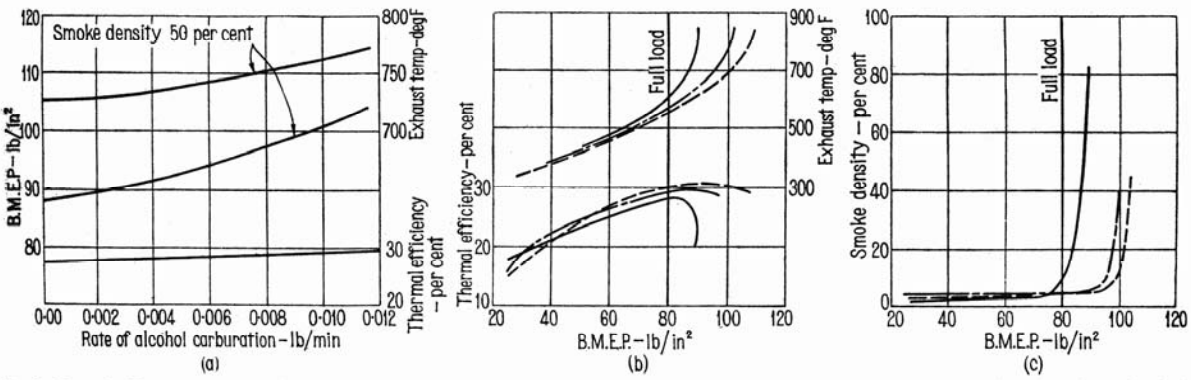

Fig. 2. Ricardo E6 engine run under the same conditions as in Fig. 1 except that the injected fuel is Grade B oil with and without alcohol carburation

——————— Grade B oil. — — — — — — — — Grade B oil with 0·01 lb/min alcohol carburation
- - - - - - - - - Grade B oil with 0·012 lb/min alcohol carburation

TABLE 2. 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 cm^3
Compression ratio	21·22 : 1
Rated power	4·2 b.h.p. at 1,250 r.p.m
Tappet clearance: inlet	0·006 in
exhaust	0·008 in.
Inlet valve opens	9 deg B.T.D.C.
Inlet valve closes	37 deg A.B.D.C.
Exhaust valve opens	44 deg B.B.D.C.
Exhaust valve closes	5 deg A.T.D.C.
Fuel injection pressure	100 atm
Fuel injection timing	37 deg B.T.D.C.
Injector	C.A.V. type DN 12 SD 12
Fuel pump	C.A.V. type PEIB 5·5 mm diameter plunger
Combustion chamber	Ricardo Comet Mk II—compression swirl

In addition to acting as a combustion accelerator, alcohol was expected to act as a thinning agent that 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 tried out first. However, alcohol-diesel blending did not produce the expected results, so it was decided to change over to carburation of alcohol and injection of diesel fuel. This stage of the work was more successful.

Alcohol as a blend with diesel fuel in high speed diesel engines

Preparation of blends of alcohol-diesel fuels: It is common experience 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 because the molecular weight gradually increases with weight of fuel, from distillate gas oil to residual oil. In the Table 1 details are given of the experimental results obtained regarding miscibility of B.S.S. Grade A, B.S.S. Grade B and furnace oils.

These experiments indicate that Grade A oil is miscible with alcohol to a maximum extent and mixing is facilitated by heating the blend to about 60 deg C. However, traces of water added to the blend, whether cold or hot, separate the components. With the 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 per cent and 5 per cent alcohol and the rest Grade A or Grade B oil.

Engine tests with alcohol-diesel fuel blends: These blends were used as fuels first in a Ricardo Research Engine with a diesel head and later in a Kirloskar-Petter, high speed diesel engine with a precombustion chamber. The results of the Ricardo engine trials are presented graphically in Figs. 1a, 1b and 1c. The tests revealed that there was no noticeable improvement in combustion, exhaust smoke density or in the running characteristics of the engine. The results from the Kirloskar-Petter engine trials are not shown, since they were similar to the others.

Alcohol as a supplementary fuel in high speed diesel engines

The results obtained with alcohol-diesel fuel blends, although good enough in certain respects, were not exactly what was expected. It was therefore decided to try carburation of alcohol with injection of different diesel fuels.

Tests with Ricardo Research Engine: These tests were limited to injection of Grade B diesel fuel and carburation of alcohol. Table 2 gives the specifications of the Ricardo Research Engine. The unit was fitted with the precombustion chamber diesel head, which was locked so that the apparent compression ratio was 21·22 : 1. Fuel was injected through a pump incorporating a device to adjust the injection timing, and alcohol was introduced through a variable jet carburettor into the induction manifold. Each fuel system incorporated a separate flowmeter to measure consumption, and the air flow was measured by Alcock viscous flow, air meter. A C.R.C. photoelectric smoke meter was used to measure the smoke density. Power measurements were made with a Farnborough electric engine indicator and an electric dynamometer. Other standard instruments were used to measure the speeds, temperatures, etc.

Test procedure: The engine was started on diesel fuel and allowed to warm up thoroughly. It was then loaded to a predetermined value. The injection timing was set at 37 deg B.T.D.C. for optimum results. Cooling water temperature was maintained at 70 deg C at the outlet from the engine. At steady running conditions one set of the following readings was taken:

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

Maintaining the load constant, the supply of diesel fuel was gradually reduced, and alcohol inducted in suitable proportions. For each combination of alcohol and diesel fuel, the engine was run at steady conditions and the various observations were recorded as before. Incipient knocking indicated the upper limit to which the propor-

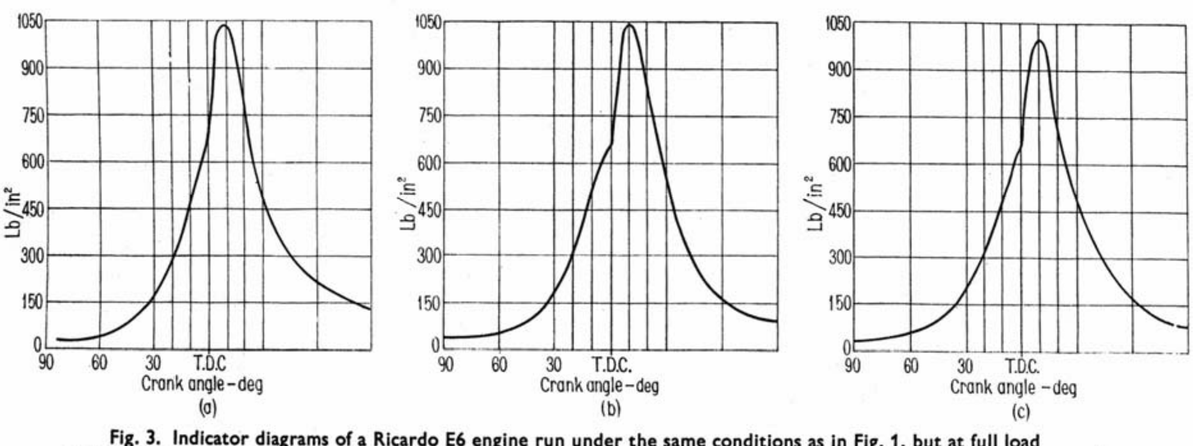

Fig. 3. Indicator diagrams of a Ricardo E6 engine run under the same conditions as in Fig. 1, but at full load
a With Grade B oil fuel injected. b With Grade B oil fuel injected and 0·01 lb/min alcohol carburetted
c With Grade B oil fuel injected and 0·012 lb/min alcohol carburetted

tion of alcohol could be increased. This procedure was repeated for different loads.

Test results: Test results are graphically presented in Figs. 2a, 2b, 2c, and 3a, 3b and 3c, and summarized as follows:

1. The maximum quantity of alcohol that could be inducted was 36 per cent of the fuel required by the engine at full load. This was found to be equivalent to an air : alcohol ratio of 54 : 1. It was also noticed that the engine began to misfire at idling if the mixture was made richer than 54 : 1.
2. As a result of induction of alcohol, the engine could be overloaded by more than 16 per cent, and under overload conditions, the smoke density was no more than that at full load with neat diesel fuel, Figs. 2a and 2b.
3. A direct inference from these overload characteristics was that the air utilization factor was higher with alcohol induction, as compared to normal running conditions.
4. Except at very light loads, there was a small but distinct increase in thermal efficiency as a result of the induction of alcohol. This value increased as the percentage of inducted alcohol was increased, Figs. 2a and 2b.
5. There was no perceptible change in the volumetric efficiency.
6. The smoke density was reduced considerably as a result of the induction of alcohol. For any particular load the higher the rate of alcohol inducted, the lower the smoke density, Figs. 2a and 2c. At full load, with induction of maximum quantity of alcohol, the exhaust colour was comparable with that of a petrol engine.
7. There was a distinct drop in the exhaust gas temperature when alcohol was inducted, Figs. 2a and 2b.

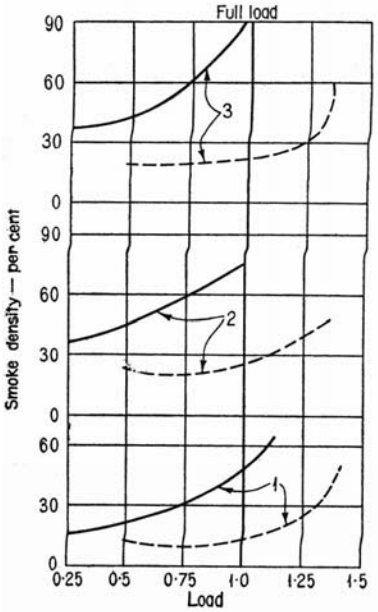

Fig. 4b. Petter engine run under the same conditions as in Fig. 4a
1 Grade A oil. 2 Grade B oil
3 Furnace oil
——————Neat hydrocarbon fuel
- - - - - - - with Alcohol carburation

Tests with a Petter engine: Because of the promising results obtained from the Ricardo engine trial, the investigation was extended to a production engine with an open combustion chamber. For this purpose, a Petter AV1 series II engine, developing 5 b.h.p. at 1,500 r.p.m., was chosen. Detailed specifications of the engine are given in Table 3.

Fuel control was effected by a centrifugal governor. A three-way cock was fitted to the fuel inlet of the injection pump so that 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 cool after leaving it. A variable jet, industrial carburettor, through which the alcohol was inducted, was fitted to the inlet manifold.

Flow-meters were used to measure the consumptions of the fuels, and air flow was measured first with an air box, and later checked with an Alcock flow-meter. Exhaust gas temperature was measured as close to the engine as possible, and a C.R.C. photoelectric smoke-meter was used to estimate the smoke density. A rough estimate of the extent of the carbon particles in the exhaust gas was made by collecting them on a glass plate which was then photographed. The cooling water temperature was maintained at about 80 deg C throughout the tests. Power measurement was effected by means of a water brake directly coupled to the engine.

The fuels chosen for the tests were:

1. B.S.S. Grade A diesel fuel, fufilling 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, produced by Mysore Sugar Factory, Mandla.

Detailed specifications of these fuels are given in Table 4.

Fuels B.S.S. Grade A and B flowed freely at room temperature; they were supplied to the injection pump after filtration. Furnace oil was too viscous *at room temperature for use with the* injection equipment. It was therefore preheated to 90 deg C and passed through three felt filters before it was transferred to the engine fuel tank. This fuel was again heated in a water *bath to about* 95 deg C before it was passed to the injection pump. The specific gravity of this fuel at various temperatures was also determined

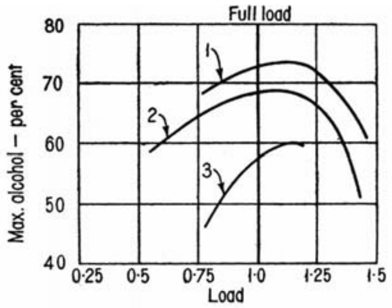

Fig. 4a. Petter engine: Compression ratio 16·5 : 1. Speed 1,500 r.p.m. Injection timing 27 deg B.T.D.C.
1 Grade A oil. 2 Grade B oil
3 Furnace oil

experimentally and was used in the calculation of fuel consumption.

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. With the engine running steadily, the following readings were taken: (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) Carbon particles in the exhaust gas were collected on a glass plate for 15 seconds and then photographed.

With the brake load constant, 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*

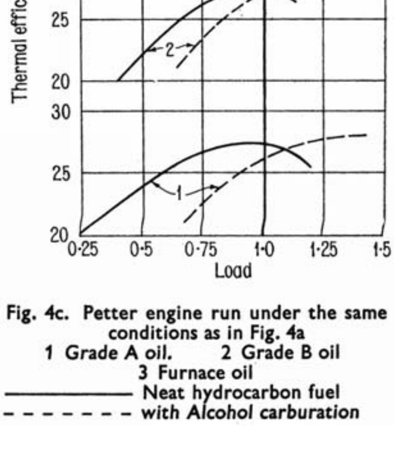

Fig. 4c. Petter engine run under the same conditions as in Fig. 4a
1 Grade A oil. 2 Grade B oil
3 Furnace oil
—————— Neat hydrocarbon fuel
- - - - - - - with Alcohol carburation

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 flowmeter reading. This procedure was repeated for half, three-quarters, full and overload conditions. The "full load neat fuel smoke density" was the limit up to which the engine was overloaded for each fuel.

Test results: The test results are graphically presented in Figs 4a, 4b, 4c, 5, 6 and 7, and summarized below:

1. Under full load conditions nearly 70 per cent of alcohol could be inducted in combination with Grade A fuel. On the other hand, under the same load conditions, only 60 per cent 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. 4a.
2. With alcohol induction, the engine could be overloaded to about 45 per cent and 40 per cent respectively with Grade A and Grade B fuels. Under overload conditions the smoke density was no more than that at full load with neat diesel oil. When running on neat furnace oil, however, it was found that the engine could be loaded only to 50 per cent for passable smoke density, Fig. 4b.
3. A direct inference from result (2) was that the air utilization factor was higher with alcohol induction, as compared with normal running conditions.
4. Under 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 carburation. On overload, there was a definite improvement in thermal efficiency, Figs. 4c and 5.
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, Fig. 6. 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 with that of a petrol engine.
7. Exhaust temperature generally increased slightly with the induction of alcohol except when furnace oil was used; with this oil it decreased slightly at higher loads, Fig. 7.
8. The proportion of free carbon particles in the exhaust gas was lower with alcohol induction. This was very pronounced in the case of furnace oil.

TABLE 3. SPECIFICATIONS OF PETTER AV1 SERIES II ENGINE

General details	Four-stroke, compression ignition, vertical, cold starting, water cooled
Number of cylinders	1
Bore diameter	80 mm (3·15 in)
Stroke	110 mm (4·33 in)
Swept volume	553 cm^3 (33·73 in^3)
Compression ratio	16·5 : 1
Rated power	5 b.h.p. at 1,500 r.p.m.
Tappet clearance	0·007 in
Inlet valve opens	4½ deg B.T.D.C.
Inlet valve closes	35½ deg A.B.D.C.
Exhaust valve opens	35½ deg B.B.D.C.
Exhaust valve closes	4½ deg A.T.D.C.
Fuel injection pressure	2,500 lb/in^2
Fuel injection timing	24 deg B.T.D.C.
Nozzle	Three-hole, 0·24 mm diameter by 1·75 mm long stem, No. HL-S24 C 175 P 3
Fuel pump	Bryce, type A1 AA 70/55.99 No. AA 32967
Combustion chamber	Open
Fuel oil	A high grade light distillate diesel fuel in accordance with B.S.S. No. 209/1947, Class A

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. The observations are given in Table 5. The results can be summarized as follows:

1. Up to 30 per cent 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

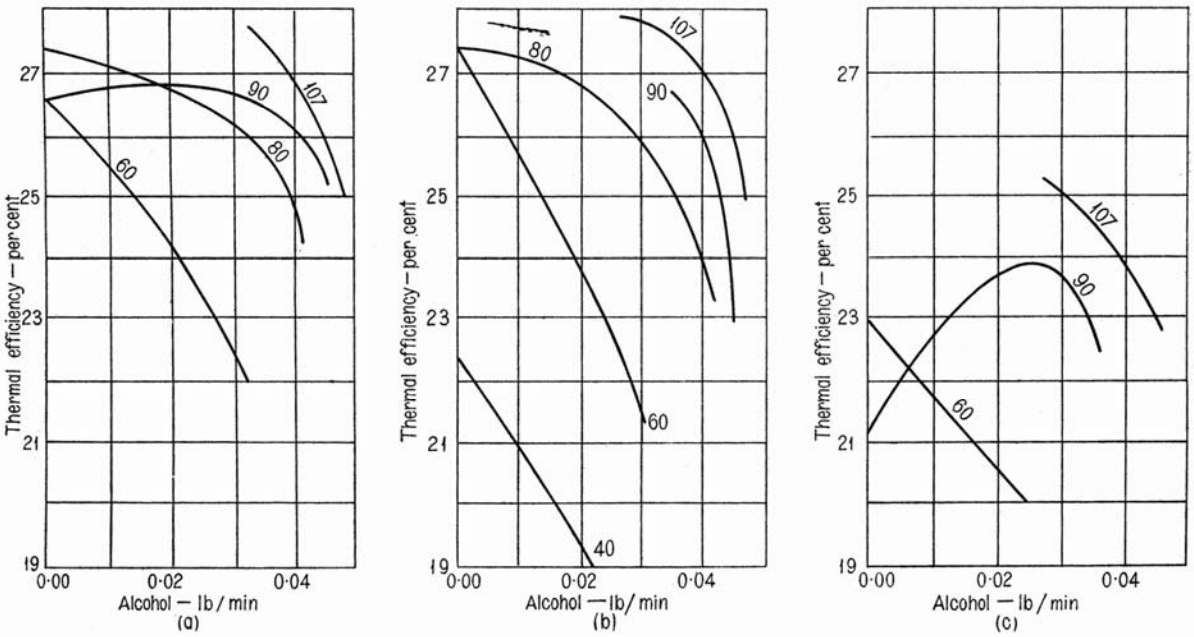

Fig. 5. Petter engine: Compression ratio 16·5: 1. Speed 1,500 r.p.m. Injection timing 27 deg B.T.D.C. Full load (80 lb/in^2 b.m.e.p.)
a Grade A oil b Grade B oil c Furnace oil

exhaust temperature. However, the trend was generally towards lower values as compared with pure alcohol.

4. There was no perceptible variation in smoke density

Discussion of results

The Ricardo engine is much less sensitive to the grade of fuel supplied, while the Petter engine is intended to run on those fuels that come within B.S.S. 209/1947 Grade A. With the Ricardo engine, the maximum amount of alcohol that can be carburetted into the engine is limited by the occurrence of knocking, whereas in the case of the Petter engine, it is limited by missing and hunting. Under all conditions of running with alcohol, the Petter engine was free from knock.

It has been noticed that, whatever the load condition, as long as the air:alcohol ratio is greater than 54:1 there will be no knocking in the Ricardo engine. As soon as the mixture is made richer, knocking starts. This may be due to the fact that enrichment of the mixture reduces the spontaneous ignition temperature and leads to auto-ignition, particularly where the compression ratio and hence the compression temperature are high. On the other hand, with the Petter engine, the compression ratio and compression temperature are 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 should also be noted that in the Petter engine, the enrichment of 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. From the curves in Fig. 8 it can be seen 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 with Grade A fuel, a maximum amount of alcohol can be utilized in the engine, and this quantity is reduced as the fuel becomes heavier.

The diesel engine, when run on carburetted alcohol with any of the three hydrocarbon fuels, gives a higher air utilization factor. Consequently, it can be overloaded to nearly 40-45 per cent when Grade A oil is used and 35-40 per cent when Grade B oil is employed. The greater the amount of alcohol carburetted, the higher is the overload that the engine can take.

In the Ricardo engine, running on Grade B oil with alcohol induction, there is a certain, though small, increase in the thermal efficiency of the engine. Figures 3a, 3b and 3c show the indicator diagrams taken at full load, on the Ricardo engine with Grade B oil alone and with Grade B oil and alcohol inducted at the rates of 0·01 lb/min and 0·012 lb/min respectively. The greater the amount of alcohol carburetted, the steeper the pressure-crank angle curve; combustion tends to be completed earlier and the peak pressure is reached earlier in the cycle: hence the increase in thermal efficiency of the engine. This may

TABLE 4. PROPERTIES OF DIESEL OILS, FURNACE OIL AND ALCOHOL USED IN THE EXPERIMENTS

	Grade A oil	Grade B oil	Furnace oil	Alcohol
Sp. gr. at 75 deg C	0·84	0·87	0·90	0·78
Cetane number	45	40	—	—
Viscosity at 100 deg F, Redwood I secs	35	45	390	—
Carbon residue Conradson, per cent weight	0·05	1·0	4·8	—
Sulphur, per cent weight	0·3	1·2	2·5	—
Water, per cent weight	Zero	0·05	0·1	Less than 0·5
Sediment, per cent weight	Zero	0·01	0·01	—
Ash, per cent weight	Zero	0·01	0·01	—
Calorific value (lower) B.Th.U/lb	18,600	18,100	18,150	11,600

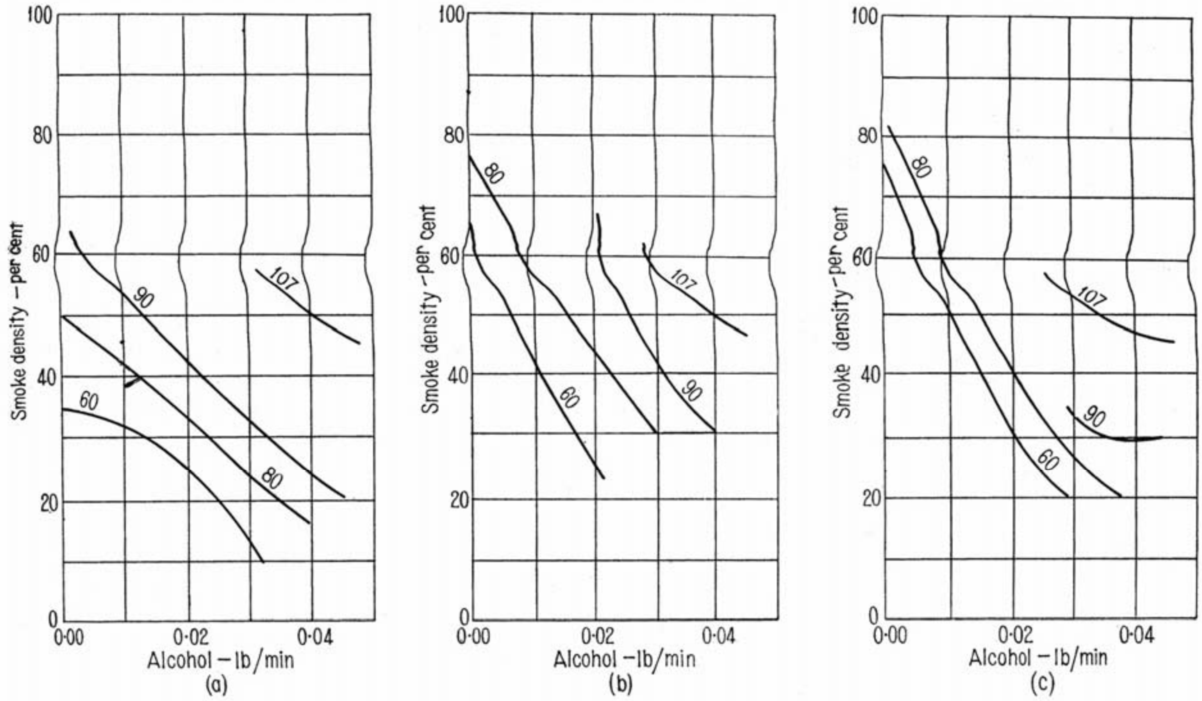

Fig. 6. Petter engine run under the same conditions as in Fig. 5
a Grade A oil b Grade B oil c Furnace oil

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

also account for the incidence of knocking with higher rates of alcohol induction than 0·012 lb/min.

With the Petter engine, the thermal efficiency generally decreases slightly with the induction of alcohol. 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.

There is no appreciable difference in the volumetric efficiency of the engine due to the induction of alcohol. From Figs. 2a, 2c and 6 it can be seen that for constant 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 burned 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 burned per cycle in the engine increases at overload, and the smoke density also increases proportionately.

The presence of free carbon particles in the exhaust is reduced considerably with the induction of alcohol. When the combustion of injected fuel is predominantly one of oxidation of products of destructive decomposition, 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. The smoke densities obtained when the Petter engine was run on furnace oil alone, and on furnace oil and alcohol, were 90 per cent and 30 per cent respectively.

As mentioned elsewhere, the principal disadvantage of alcohol-diesel fuel blends is their low water tolerance. Carburation of alcohol successfully overcomes this disadvantage. With this method of introducing alcohol, as much as 30 per cent of water in solution with alcohol does not seem to have any

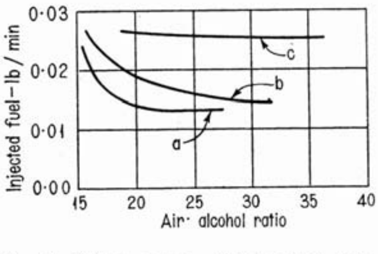

Fig. 8. Petter engine. Compression ratio 16·5 : 1. Speed 1,500 r.p.m. Injection timing 27 deg B.T.D.C.
a Grade A oil. b Grade B oil
c Furnace oil

adverse effect on the performance of the engine. The common standard of 95 per cent alcohol, which can be produced easily, is suitable for the purpose of induction into high speed diesel engines.

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 open combustion chamber high speed diesel engines, both for normal running and high power boost.
2. Under overload conditions, better 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 when alcohol is introduced is higher in the case of Grade A and Grade B oils and lower with furnace oil.
6. The presence of appreciable proportions of water in the alcohol does not affect the performance of the engine, so it is not necessary to specify anhydrous alcohol.
7. Further research will be needed to complete the investigation. Details of the work still to be carried out are given in the paper as published in the *Journal of the Indian Institute of Science*.

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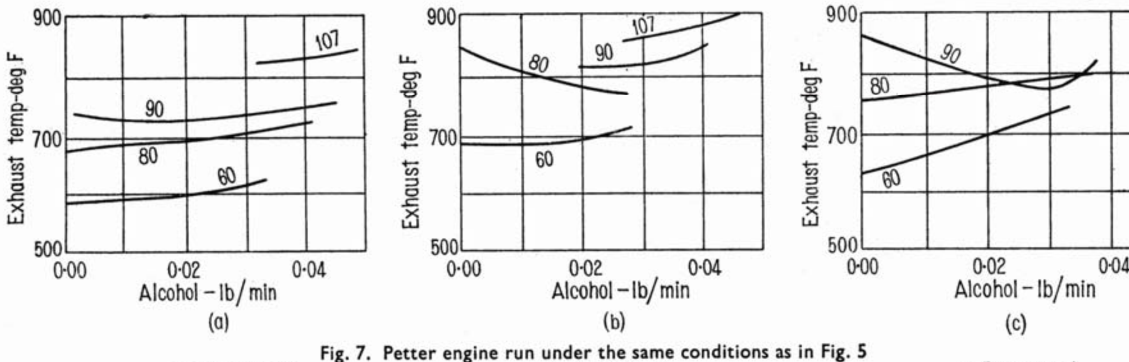

Fig. 7. Petter engine run under the same conditions as in Fig. 5
a Grade A oil b Grade B oil c Furnace oil