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Alcohol with Normal Diesel Fuels-Part II, Gas and Oil Power
H. A. Havemann, M. R. K. Rao, A. Natarajan and T. L. Narasimhan

Alcohol with Normal Diesel Fuels—Part II

The Concluding Part of a Report on Some Investigations Carried Out at the Indian Institute of Science on the Utilisation of Power Alcohol in Combination with Normal and Heavy Fuels in High-speed Diesel Engines

By Dr. H. A. Havemann, M. R. K. Rao, A. Natarajan and T. L. Narasimhan†

THE results obtained from the Ricardo engine, as outlined last month, were so encouraging that 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 2.

Test Set-up.—The test set-up for this engine is indicated schematically by line diagram 5*a* and shown in photographs in figs. 5*b* and 5*c*. The fuel control for this engine was by means of a centrifugal governor which 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.

Instrumentation

Flow meters were used to measure the consumption of the fuels as follows:

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

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 deg. C. throughout the tests.

Fuels chosen for the tests were:

1. *B.S.S. Grade 'A' diesel fuel.*—Fulfilling the maker's 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.

Detail specifications of these fuels are given in Table 3.

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

TABLE 2

Specifications of Petter AV1 Series II Engines

General details	Four-stroke, compression ignition, vertical, cold starting, water cooled
Number of cylinders	1
Bore	3·15in. (80 mm.)
Stroke	4·33in. (110 mm.)
Swept volume	33·73 cu. in. (533 cc.)
Compression ratio	16·5 : 1
Speed	1,500 r.p.m.
Rated power	5 b.h.p.
Valve tappet clearance	0·007in.
Inlet valve opens	$4\frac{1}{2}$ deg. before top dead centre
Inlet valve closes	$35\frac{1}{2}$ deg. after bottom dead centre
Exhaust valve opens	$35\frac{1}{2}$ deg. before bottom dead centre
Exhaust valve closes	$4\frac{1}{2}$ deg. after top dead centre
Fuel injection pressure	2,500 lbs. per sq. in.
Fuel injection timing	24 deg. before top dead centre
Nozzle	Three hole, 0·24 mm. dia. x 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

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 deg. F.	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, % 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

† All of the Department of Internal-Combustion Engineering, Indian Institute of Science. Dr. Havemann is the Head of the Department.

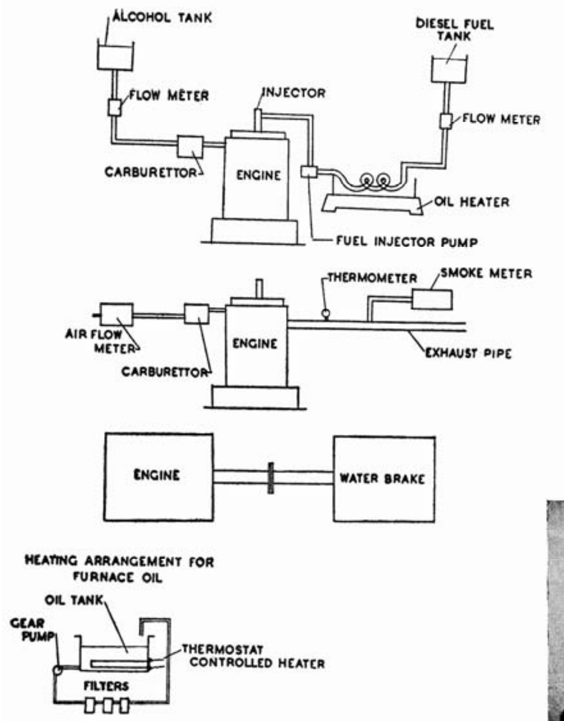


Fig. 5a (above).—Diagrammatic arrangement showing the test set up using the Petter engine

Fig. 5b (right).—General view of the Petter test unit

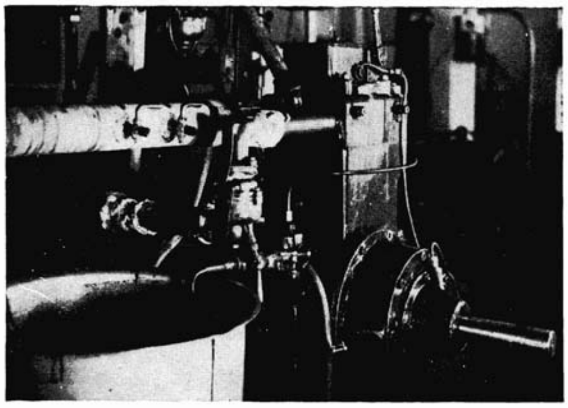
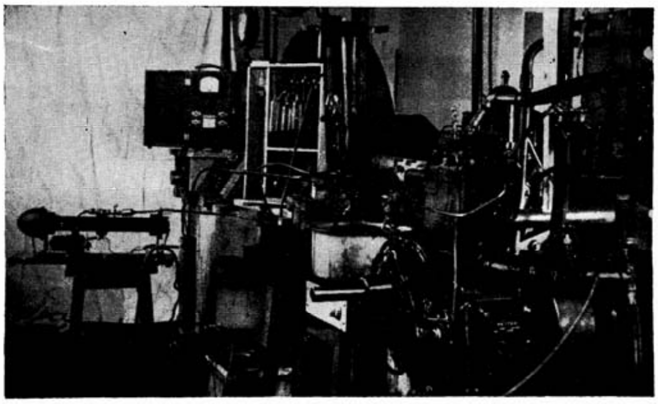


Fig. 5c.—The heating arrangement for the furnace oil used in the Petter engine tests



too viscous at room temperature to be acceptable to 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. It was again heated in a water-bath to about 95 deg 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.

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 $\frac{1}{2}$, $\frac{3}{4}$, 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. *6a, 6b, 6c, 6d, 6e, 6f, 6g* and *6h*, and summarised 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. *6a*).

2. The engine could be overloaded to about 45 per cent. and 40 per cent. 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 per cent. 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. *6b*).

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

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. *6c* and *6d*).

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. *6e*).

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. *6f*).

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. *6g* and *6h*).

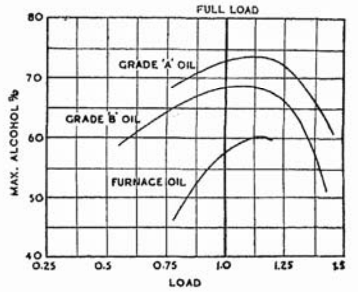
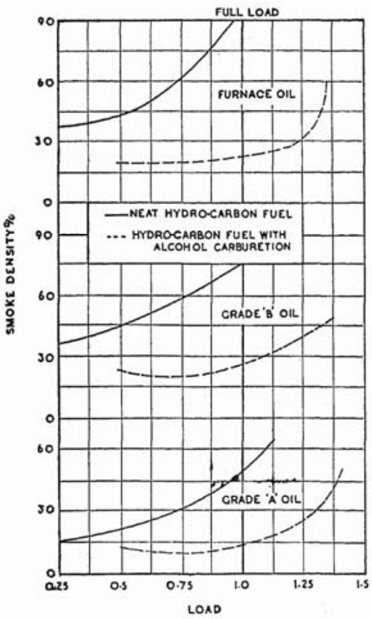
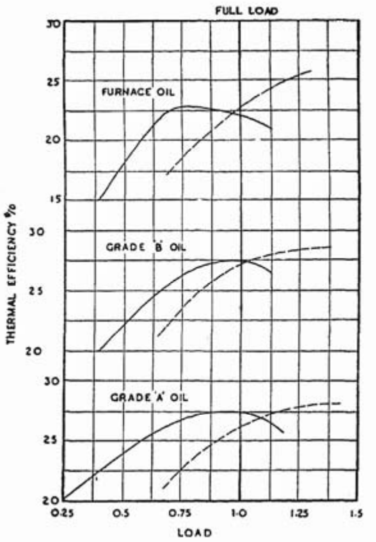


Fig. 6a (above), 6b (below) and 6c (right) show test results obtained with the Petter engine at 1,500 r.p.m. The compression ratio was 16·5 to 1 and the injection advance 27 deg. before t.d.c.
——— =Neat Hydrocarbon Fuel
– – – =Hydrocarbon Fuel with Alcohol Carburetion



Alcohol-water solution as supplementary fuels

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 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 exhaust temperature. But the trend was generally towards lower values as compared to pure alcohol.

4. There was no perceptible variation in smoke density.

Discussion of results

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.

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 to 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,

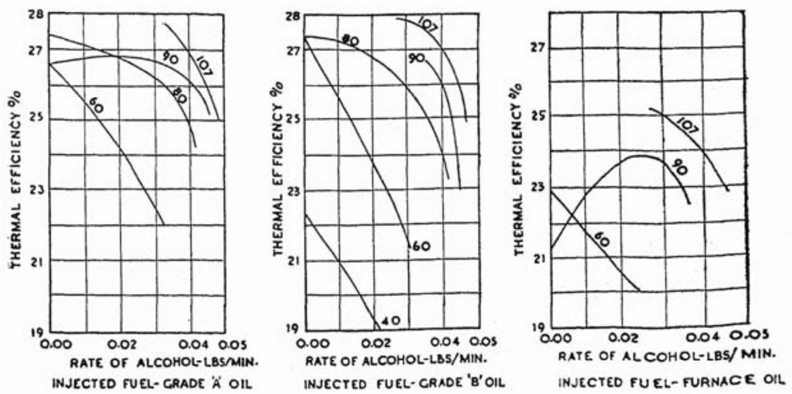


Fig. 6d.—Further test results obtained from the Petter engine at 1,500 r.p.m. and 16·5 to 1 compression ratio. The injection advance was 27 deg. before t.d.c. and the engine was run at full load 80 lb. per sq. in. b.m.e.p.

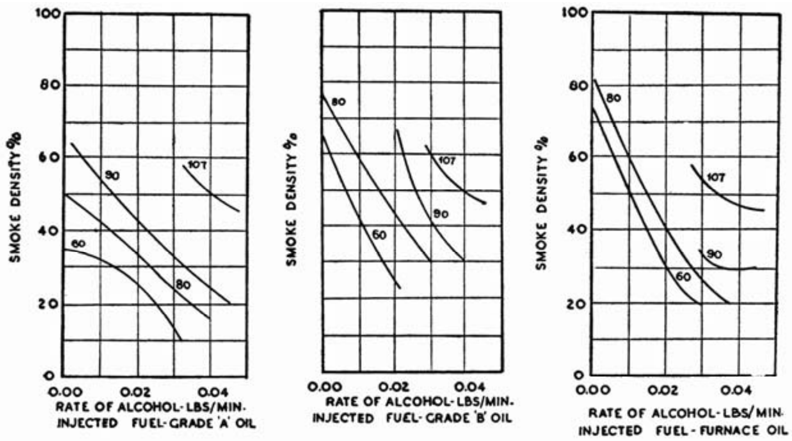


Fig. 6e.—Smoke density figures with the various fuel mixtures in the Petter engine under the same conditions as those given for fig. 6d

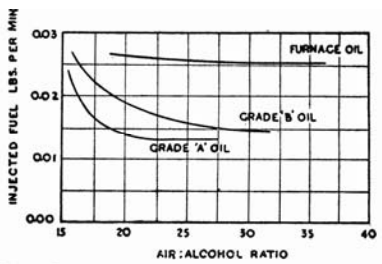


Fig. 7.—Injected fuel against air:alcohol ratio for the Petter engine. The compression ratio was 16·5 to 1, the speed 1,500 r.p.m. and the injection advance 27 deg. before t.d.c.

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 conditions, 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.

Further investigation

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. 7 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 of 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.

Overload.—The diesel engine, when run on carburetted alcohol with any of the three hydrocarbon fuels, gives a higher air utilisation factor. Consequently, the engine can be overloaded to nearly 40 to 45 per cent. in the case of Grade 'A' oil and 35 to 40 per cent. 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.

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. Figs. 4*a*, 4*b* and 4*c* show the indicator diagrams taken at full load,

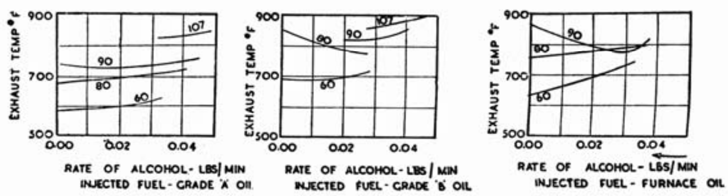
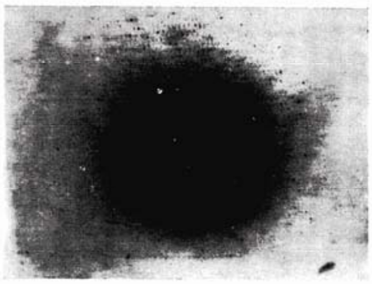
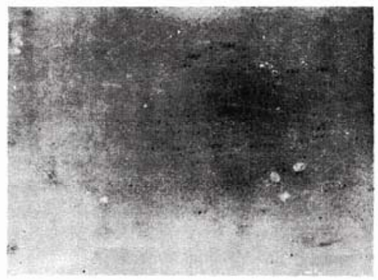


Fig. 6f.—Exhaust temperature curves for the Petter engine using the various fuel mixtures and running under the conditions given for fig. 6d.



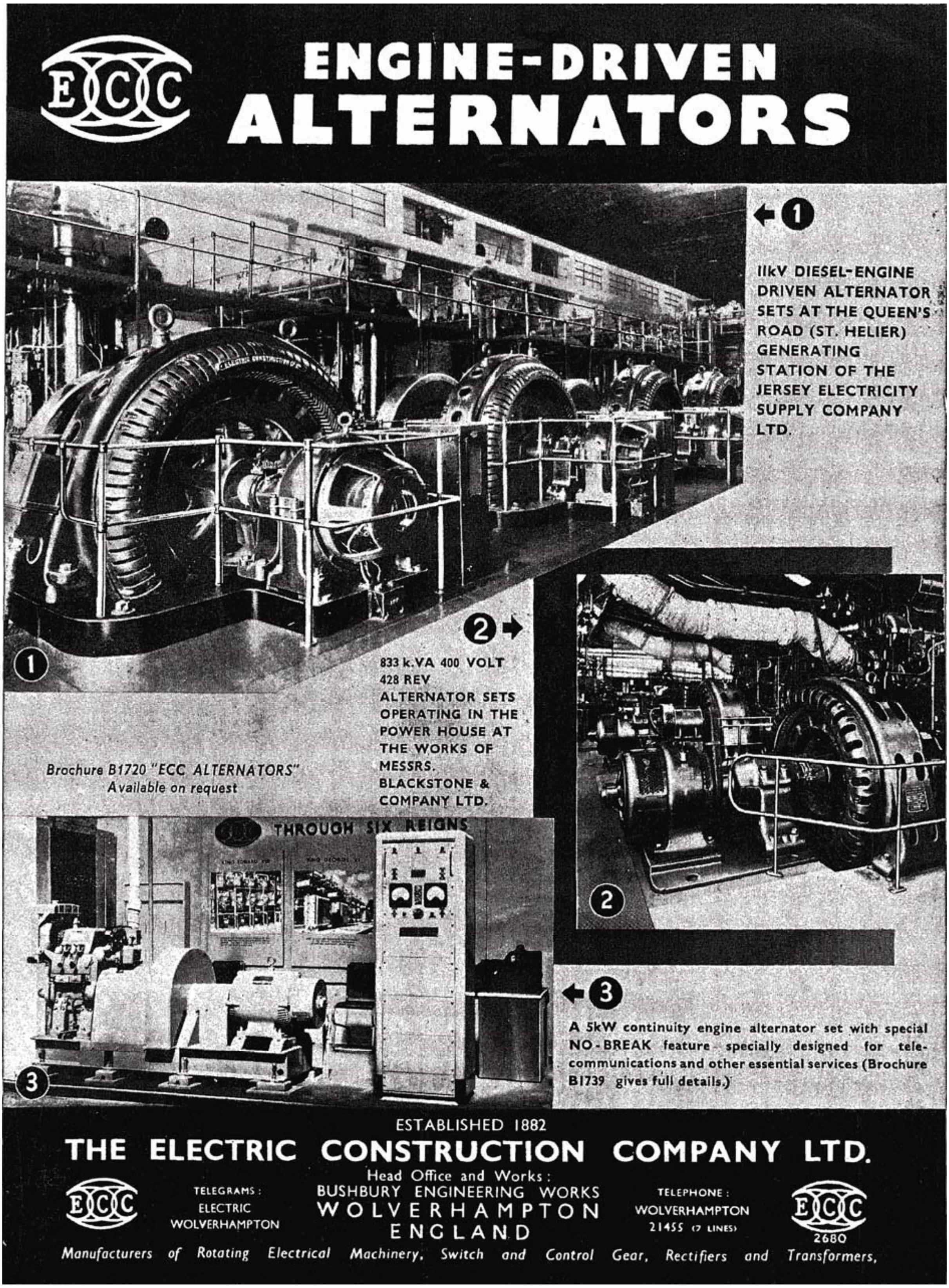


Figs. 6g (left) and 6h (right) show respectively the carbon particles in the exhaust of the Petter engine running on furnace oil at full load and on furnace oil with alcohol at full load. The particles were collected on a glass plate held in the exhaust stream for 15 seconds

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.

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

Smoke Density.—It is seen from figs. 3*a*, 3*c* and 6*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.

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. 6*g* and 6*h*. Fig. 6*g* is the photograph of carbon particles collected from the exhaust of the Petter engine running on furnace oil and fig. 6*h* is a similar photograph taken when the engine was running on furnace oil and alcohol. The corresponding smoke densities are 90 per cent. and 30 per cent. respectively.

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 per cent. 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 per cent. alcohol that can be produced easily can serve for the purpose of induction into high speed diesel engine.

Conclusions

1. Alcohol can be used as a power booster fuel in a high compression pre-combustion-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 utilisation 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.

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