FUEL RESEARCH INSTITUTE OF SOUTH AFRICA.

TECHNICAL MEMORANDUM NO. 35 OF 1966.

ALTERNATIVE FUELS FOR INTERNAL COMBUSTION ENGINES.

DOCUMENT 3/1

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Performance of a Bedford Engine on Petrol and Liquified Petroleum Gas.

3.1 Performance on petrol.

3.1.1 Preliminary adjustments.

After installation of the engine and upon completion of the running-in period, the torque and power produced were determined at full load (i.e. with the throttle fully opened) at various speeds.

The output obtained was considerably less than that given in the maker's performance data (c.f. Fig. 2.1 of Doc. 2/1), even when making allowance for the higher altitude, approximately 4,800 ft, at which the Institute is situated. The main causes were found to be that the engine, as delivered, operated on a very lean fuel/air mixture and that the ignition advance was not sufficient.

The carburettor, supplied with the engine was therefore equipped with a larger main jet No. 135 and a conpensating jet No. 125.

In order to arrive at the best ignition adjustment, the torque produced at a constant dynamometer setting (and nearly constant engine speed) was determined as a function of the ignition advance. This produced the results presented in Figure No. 3.1. It was then decided to set the initial ignition timing at 10 degrees before top dead centre; with the automatic advance operating, an advance of 35 degrees at 3,000 r.p.m. was obtained.

In practice, the mixture strength and ignition advance should be set according to the type of fuel and the duty of the vehicle; the figures selected were considered to be reasonably representative.

3.1.2 Performance .../

3.1.2 Performance.

The main characteristics of the engine, determined by the methods described in Doc. 2/1, are presented in Figure 3.2, while some numerical data are given in Table No. 3.1.

In these tests, the air/fuel ratio was determined by means of a conductivity type analyser. As a check, a few gas samples were taken and subjected to a chromatographic analysis, the results of which are given in Table No. 3.2. The results of the analysis are in good agreement with the indications of the conductivity cell, as may be judged with the aid of Figure 3.3.

This diagram, derived from Lighty's work[1)] shows the exhaust gas composition as a function of the air/fuel ratio for an engine operating on a liquid hydrocarbon, having a carbon/hydrogen ratio of 1 ÷ 0.175.

The data represent the averages of many experimental determinations and also of calculated values. The analytical results thus point to an air fuel ratio varying between approximately 12.4 ÷ 1 and 13.3 ÷ 1, which agrees well with the direct observations of Table 3.1.

The mixture ratio is therefore slightly rich, but not more so than is frequently used in practice.

Though the power generated by the engine is still not quite equal to that claimed by the manufacturer (after introducing an altitude correction of -15% to the specified data), this need not be a matter of concern. The same observations were made on nearly all engine tests carried out at the Institute in the past. The discrepancy may be caused by a higher resistance in the intake and exhaust system; also the manufacturer may have used a richer mixture and greater ignition advance.

For .../

1) Lighty: International Combustion Engines, 5th ed. p. 162 McGraw Hill Co. Inc.

Since the data of Figure 3.2 are entirely normal, this performance was accepted as the standard output of the engine on a premium grade motor fuel.

For the purpose of comparison with other fuels, it may be mentioned that the carburettor temperature was always higher than the ambient temperature, the difference varying from 5°C at low speeds to 10°C at high speed.

The exhaust temperature varied from a figure of 550°C at 500 r.p.m. to 780°C at 3,000 r.p.m. (also see Figure 3.7).

Upon completion of these tests (and the experiments on L.P.G. mentioned hereafter in section 3.2), the engine was dismantled and the main dimensions taken. These data were presented in Table 2 of Doc.2, and are repeated here as Table No. 3.3.

A sample of the test fuel was retained for future reference and some of the engine oil which had been subjected to 47 hours of operation, was retained for future comparison with the engine oil after operation on producer gas.

3.2 PERFORMANCE .../

3.2 PERFORMANCE OF BEDFORD ENGINE ON LIQUIFIED PETROLEUM GAS.

3.2.1 Some remarks on operation on L.P.G.

In a fairly large engine, such as the Bedford, the rate of fuel consumption is of the order of one pound per minute at full load. At such a rate, it is not feasible to exhaust the fuel from the storage cylinder in the gaseous state since the heat of evaporation is then supplied by the fuel remaining in the reservoir. An excessive temperature drop occurs which causes difficulties in operation, such as low gas pressure and fractional distillation, causing a gradual change in gas composition.

The fuel is therefore drawn off in the liquid state and passes through a combined pressure reducer and externally heated evaporator. The heat required is usually supplied by the cooling water, leaving the radiator. The gas is then passed through a carburettor where the combustion air is admitted. The air/fuel ratio can be altered by changing a nozzle or venturi.

Figures 3.4 and 3.5 give some details of the construction of these devices.

Some data on L.P.G. are given in Table No. 3.6.

3.2.2 Adjustment of engine.

The conversion equipment and gas cylinders, required for the experiment, were put at the disposal of the Institute by Messrs. A.D.C. Engineering, importers of the "Beam" gas carburettion unit. Technicians of this firm also carried out the installation and adjustment of this equipment. For the purpose of these experiments it was considered to be expedient to allow the suppliers of the equipment to do this to their own satisfaction and without the intervention of the Institute.

The carburettor was initially equipped with a No. 46 Venturi. As the output obtained was appreciably lower than with petrol, the supplier of the equipment decided to use a No. 40 Venturi. He also installed an insulating plate between the mixer and the manifold and further advanced the ignition timing.

3.2.2. Performance .../

3.2.2. Performance.

A series of experiments was carried out after these preliminary trials. The fuel used in these test runs was a nominal 70% propane: 30% butane mixture obtained from Messrs. African Oxygen Ltd., Pretoria; an analysis indicated that the actual proportions were 68.2% propane, and 31.8%butane. The calculated nett calorific value of this fuel is 10,870 kcal/kg.

The results of several trial runs are shown in Figure 3.6, while Table 3.4 presents some numerical data. Most of the data can be represented by a regular curve, the cause of the appearance of some spurious results is mentioned below.

In these experiments, the air/fuel ratio was calculated from the observed air flow and fuel flow rates. This procedure indicated that the air/fuel ratio was very rich; the theoretical figure is 15.6 ÷ 1, in practice a ratio between 12.5 ÷ 1 and 14 ÷ 1 is usually adhered to.

Some exhaust gas samples were drawn; the analysis, reported in Table No. 3.5 confirms that the mixture was unduly rich.

It was observed that at high fuel consumption rates, the carburettor temperature dropped below freezing point. An ice deposit was formed on the outside of the carburettor and must consequently also have been present in the interior passages. The air and gas flow were consequently impeded and the proper operation of the engine upset. This is the explanation for the misplaced points in the diagram. When operation of the engine was continued under these conditions, an appreicable drop in power occurred and the engine ultimately stalled unless the load was reduced.

On the test bed, these difficulties could be largely eliminated by reducing the rate of cooling water circulation, so that the temperature was raised.

It is doubtful whether the same trouble would be experienced in practice if the cooling water temperature is controlled by a thermostat, and when an engine hood is present so that the hot air from the radiator flows over the evaporator. A road test could settle this point.

Cold .../

Cold and hot starting presented no difficulties. When starting in the cold condition, full power was immediately available.

Acceleration and operation under rapidly fluctuating loads cannot be judged from the test bed performance.

The carburettor temperature was consistently lower than the ambient temperature, that of the exhaust gases was appreciably lower than for petrol (c.f. Figure 3.7), though both effects may probably have been exaggerated because of the rich mixture supplied to the engine.

3.2.3. Comparison with operation on petrol.

The diagram, Figure 3.6 indicated that at high engine speeds, the power produced by L.P.G. was less than that obtained with petrol. On the basis of the calorific value of the theoretical air/fuel mixtures (10,870 kcal/Nm^3 for L.P.G., 10,800 kcal/Nm^3 for petrol), one would expect almost the same output. Since the low intake temperature increases the volumetric efficiency of the engine, a rather higher output could be obtained in principle. The engine was thus not yet adjusted to maximum output. This is not surprising since the air/fuel mixture was unduly rich, and the full advantage of the high octane rating of L.P.G. (which is between 100 and 130, depending on the propane: butane ratio) was not realised; the ignition advance was the same as that used for petrol.

3.2.4. Conclusion and further action.

Though it would be desirable to perform a further test run with better engine adjustments, this experiment was deferred for the following reasons:

i. The investigation of the properties of L.P.G. forms a fairly minor part of the test programme and the engine had to be prepared for operation on producer gas.

ii. Further experiments could better be performed during a period of hot weather — these reported were performed at ambient temperatures of 6°C to 16°C.

iii. The information obtained from these tests already indicates that L.P.G. is an entirely acceptable motor fuel.

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PRETORIA. 8/9/66.

TABLE NO. 3.1

Performance of Bedford Engine on Petrol.

Engine Speed r.p.m.	Fuel Rate kg/min.	Air/Fuel Ratio	Torque mkg	Power HP	Thermal Efficiency %	Ignition Advance degrees
3330	0.436	12.7	17.50	81.1	18.2	36
2354	0.352	13.3	23.75	78.0	21.7	30
1962	0.290	13.4	24.00	65.4	21.8	27
1628	0.238	13.5	25.00	56.7	23.3	25
1009	0.157	13.6	26.00	36.6	22.8	20
474	0.060	14.3	24.00	16.1	26.5	15
967	0.156	13.6	27.75	37.4	23.5	19
1569	0.231	13.1	25.00	54.7	23.2	24
2110	0.314	12.8	24.00	70.6	22.0	29
2496	0.364	12.6	23.25	80.9	21.8	32
2571	0.372	12.6	23.25	83.5	22.0	32
3142	0.430	12.4	19.50	85.4	19.5	36
3421	0.426	11.9	17.00	81.1	18.7	36

Data obtained in Test 14. Fuel: Mobilgas Premium
Air/Fuel Ratio: by Hartmann & Braun Gas Analyser.
Efficiency based on an assumed nett calorific value of 10,800 kcal/kg

TABLE NO. 3.2

ANALYSIS OF EXHAUST GAS SAMPLES
ENGINE OPERATING ON PETROL

Sample No.	CO %	CO_2 %	Approx. Engine Speed.
1	4.0	12.0	3,000
2	4.5	11.0	2,000
3	5.0	9.5	1,500
4	5.5	12.0	1,000
5	6.0	11.0	3,000
6	5.0	12.0	2,000
7	5.0	12.0	1,000
8	4.0	10.0	1,000

TABLE NO. 3.5

ANALYSES OF EXHAUST GAS SAMPLES
ENGINE OPERATING ON L.P.G.

Sample Number	H_2O %	CO %	CH_4 %	CO_2 %	Approx. Engine Speed r.p.m.
1*	7.0	13.0	0.5	3.5	3,000
2	4.5	9.00	0	7.5	1,000
3	6.5	12.00	0	6.0	2,000

* Carburettor starts icing up.

TABLE NO. 3.3

DIMENSIONS OF BEDFORD ENGINE, AS MEASURED AFTER RUNNING-IN PERIOD

Piston diameter	3.872 in.	98.349 mm
diameter, top	3.877 "	98.476 mm
" middle	3.879 "	98.527 mm
" bottom	3.880 "	98.552 mm
Ring Gap	0.014 "	0.356 mm
Crank diameter	2.375 "	60.325 mm
Bearing Cup	2.376 "	60.350 mm
Valve stem dia.	0.316 "	8,026 mm
Valve guide dia.	0.320 "	8.128 mm
Volume Cylinder Head	8.06 cu.in.	132.0 cm^3

Cylinder Number	Height of Head inches	mm	Compression lb/sq.in.	Kg/cm^2
1	0.825	21.2	118	8.29
2	0.823	20.9	113	7.95
3	0.810	20.6	115	8.09
4	0.807	20.5	115	8.09
5	0.835	21.2	110	7.73
6	0.823	20.9	110	7.73

TABLE NO. 3.4

PERFORMANCE OF BEDFORD ENGINE ON L.P.G.

Engine Speed r.p.m.	Fuel Rate kg/min	Air/Fuel Ratio kg/kg	Torque m k g	Power H P	Thermal Efficiency %	Ignition Advance (degrees)
930			23.30	29.4		21
980			24.00	31.6		
1090			24.50	37.2		25
1390			24.50	47.5		27
1485	0.264	10.40	25.00	51.7	19.1	
1515			23.75	50.2		
1870			22.75	59.4		
1913	0.349	10.45	22.50	60.0	16.8	
2280			21.25	67.6		36
2360	0.430	10.10	20.75	68.3	15.5	
2390			20.30	67.6		
2390			20.25	67.2		36
2460			20.00	68.6		34
2470			20.10	69.4		
a) 2705	0.486	10.00	20.25	76.3	15.3	
2800			20.00	78.2		38

Data obtained in tests 4, 5, and 6.
Thermal efficiency based on calculated nett calorific value of 10,870 kcal/kg
a) Carburettor starts icing.

TABEL NO. 3.6

SOME DATA ON PROPANE, BUTANE AND OCTANE.

FUEL		PROPANE C_3H_8	BUTANE C_4H_{10}	OCTANE C_8H_{18}
Boiling Point	°C	-44.5	-0.5	+114
Density, Gas	kg/m^3	1.97	2.59	5.09
Density, Liquid	kg/litre	0.59	0.6	0.7
Gross Calorific Value	kcal/kg	11,850	11,600	11,400
	B.ThU/lb	21,300	20,900	20,500
Nett Calorific Value	kcal/kg	10,900	10,800	10,800
	B.ThU/lb	19,600	19,450	19,450
Theoretical Air/Fuel Ratio	kg/kg	15.7	15.5	15.2

L.P.G. is a mixture of propane and butane

Octane figures may be taken as an approximation for petrol.

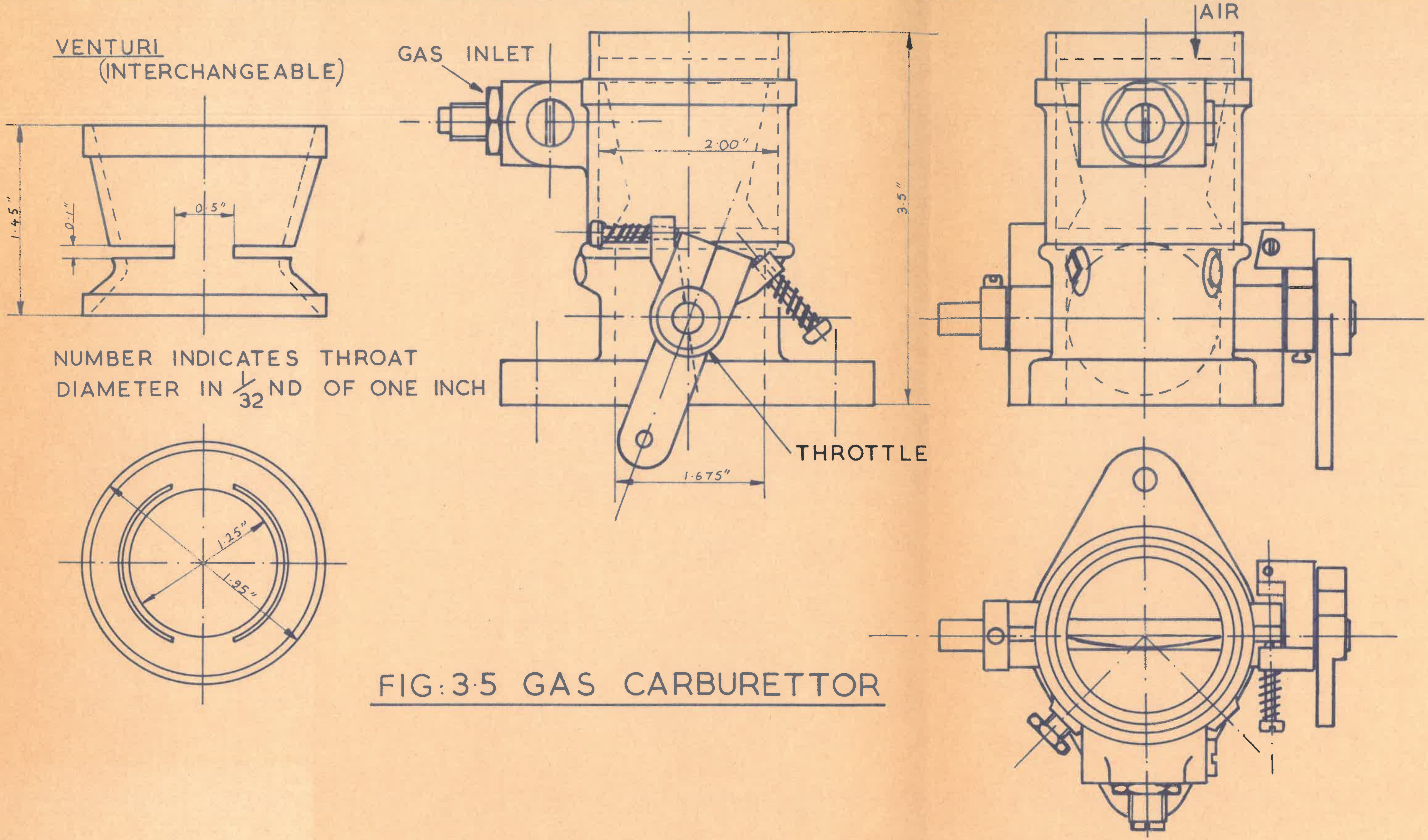

FIG: 3·5 GAS CARBURETTOR

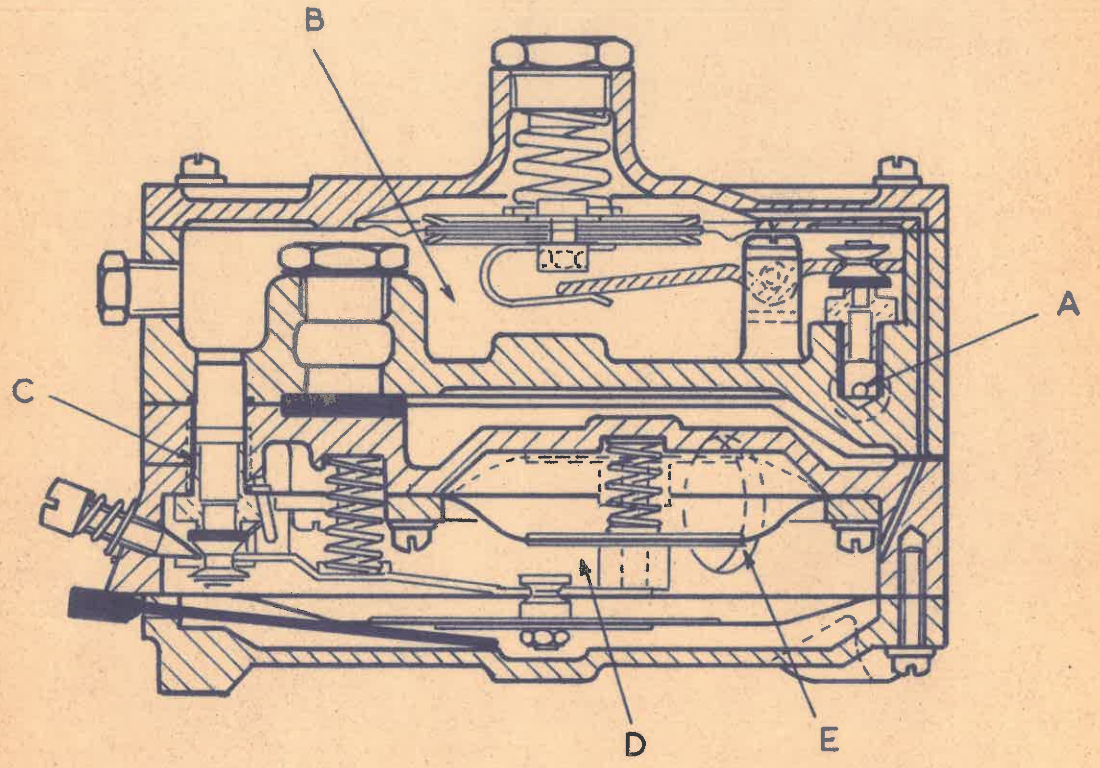

FIG: 3·4 LPG VAPORISER

EXHAUST PRODUCTS FOR VARIOUS AIR-FUEL RATIOS

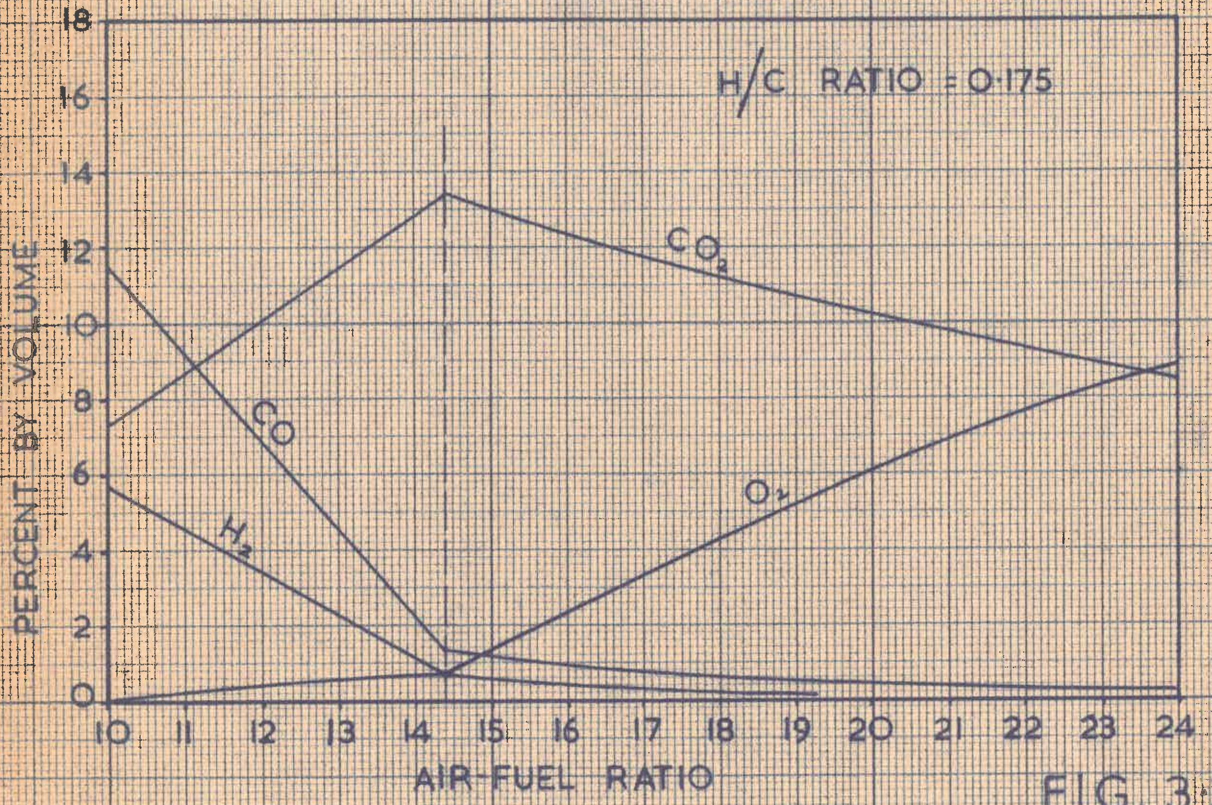

FIG. 3.3

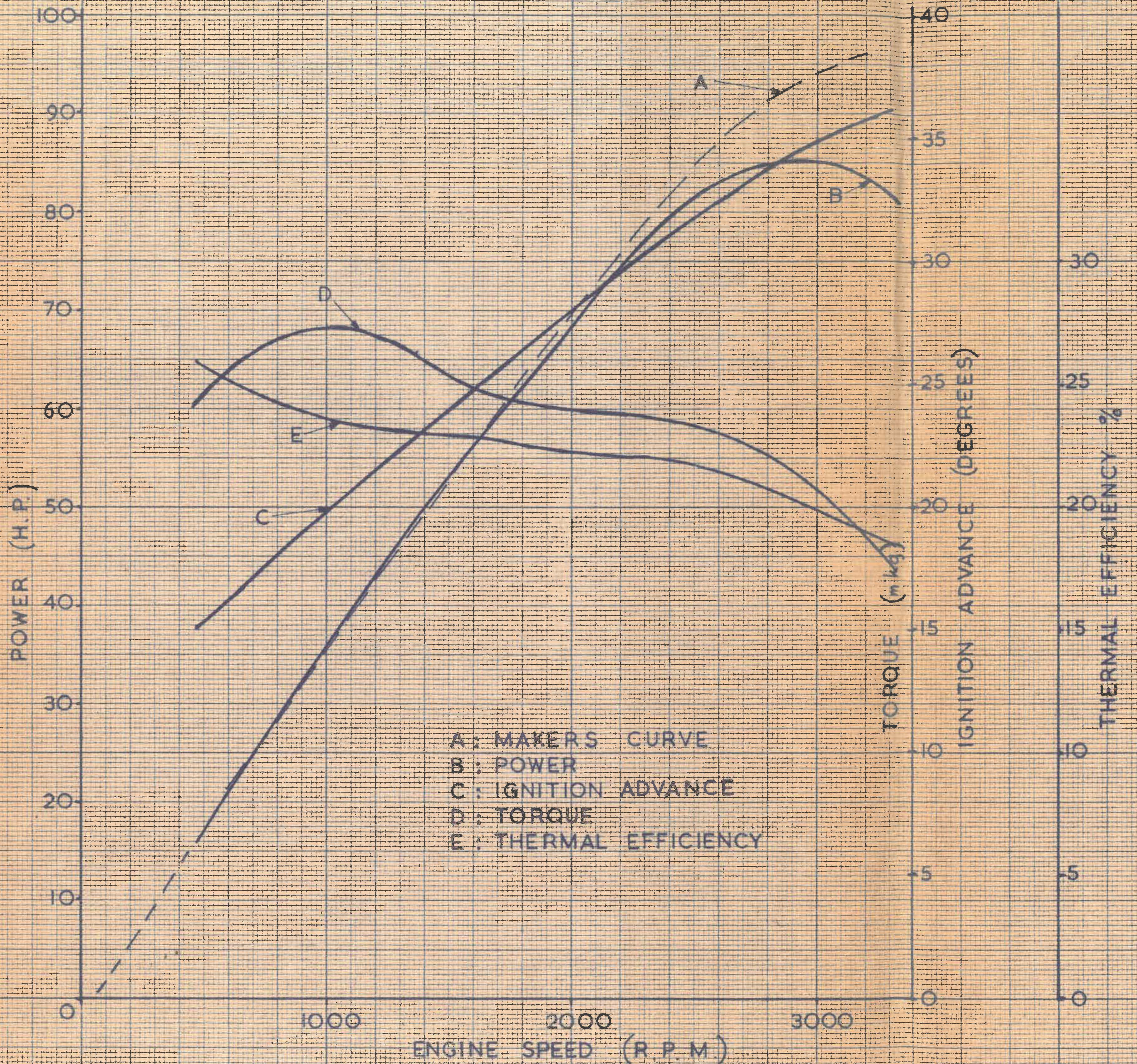

FIG. 3·2 : OPERATION OF BEDFORD ENGINE ON PETROL

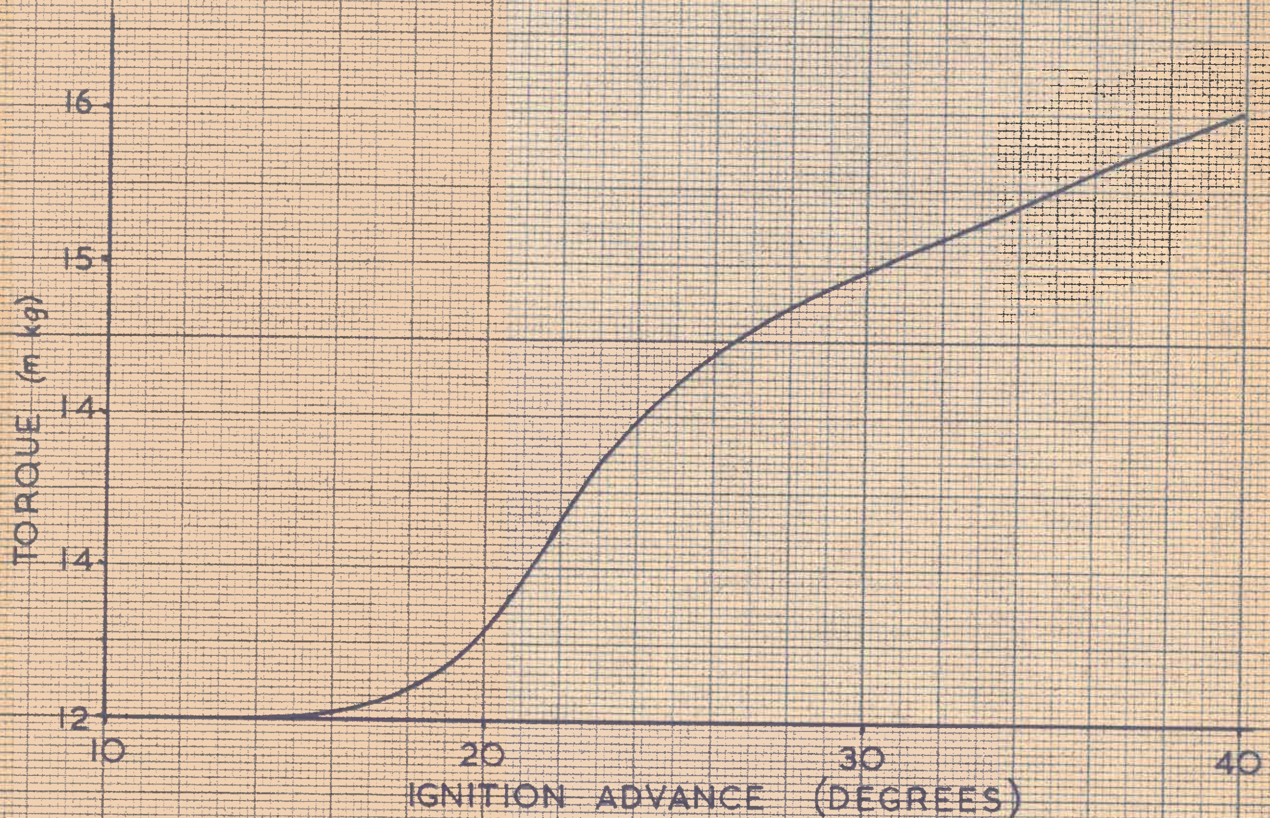

FIG: 3·1 EFFECT OF IGNITION ADVANCE ON TORQUE

FUEL: PETROL; MEAN SPEED: 1730 r.p.m.