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FUEL RESEARCH INSTITUTE
OF SOUTH AFRICA

ONDERWERP:
SUBJECT: THE DUAL-FUEL OPERATION OF A DIESEL ENGINE, USING ETHYL ALCOHOL AS THE SECONDARY FUEL

AFDELING:
DIVISION: ENGINEERING

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FUEL RESEARCH INSTITUTE OF SOUTH AFRICA

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~~RESTRICTED CIRCULATION~~

THE DUAL-FUEL OPERATION OF A DIESEL ENGINE USING ETHYL ALCOHOL AS THE SECONDARY FUEL

1. INTRODUCTION

In view of the desire to conserve oil products, it was decided to attempt to use ethyl alcohol in the place of petrol in a duel-fuel operated diesel engine. Apart from the change of fuel, test conditions have been as described in Report No. 51 of 1977 - 'Reducing fuel consumption and smoke emission of diesel engines'.

Owing to differences between the properties of ethyl alcohol and petrol, some problems were anticipated in the work. (Table 1 presents a summary of the properties of the ethyl alcohol methyl alcohol, petrol and dieselene). The first of these problems was higher fuel consumption due to the lower calorific value of ethyl alcohol. The second was the additional cooling of the compressed air for ignition, due to the higher latent heat of ethyl alcohol.

2. PRELIMINARY TESTS

A series of preliminary tests, in which only the torque was measured, were carried out in order to determine the optimum dieselene and ethyl alcohol settings. Details of the settings used, together with the test sequence, are given in Table 2. Figure 1 shows the results in graphical form, together with some earlier test results as detailed below:

a) Derated diesel engine (7,5 mm dieselene stop).
b) Normally operated diesel engine (11,4 mm dieselene stop).
c) Derated diesel engine (7,5 mm dieslene stop) + petrol enriched air (35 jet).

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From the torque curves for the different fuels and engine settings of Figure 1, it can be seen that the maximum torque is obtained using the following combination: a 8,5 mm dieselene pump stop, a 90 ethyl alcohol jet, and a 3,0 needle position.

Note: The jet sizes and needle positions quoted, are on an empirical basis.

3. MAIN TESTS

Following the preliminary work, a number of complete tests were carried out. The results of these tests are presented in Table 3. They confirm the optimum setting given earlier.

In further test work, the optimum setting was again used, and compared with a number of other operational systems as described below:

a) 7,5 mm pump stop, dieselene only (derated operation);
b) 8,5 mm pump stop, dieselene only (derated operation);
c) 11,4 mm pump stop, dieselene only (normal dieselene operation);
d) 7,5 mm pump stop + 35 jet petrol enriched air (dual-fuel operation).

The results of this work are summarised in Table 4, and in order to provide greater detail, log sheets of three of the more important tests are appended. These are:

Test No. 1P, 17/6/77 - petrol-enriched diesel engine.
Test No. 11E, 18/10/77 - ethanol-enriched diesel engine.
Test No. 10D, 18/10/77 - normal diesel engine.

Table 5 compares the operation of a normal diesel engine with a derated petrol-enriched engine, and Table 6 compares the normal diesel engine with a ethanol-enriched engine.

4. COMMENT

(1) The results of the final series of tests (Table 4) show that it is possible to use ethyl alcohol as the secondary fuel to dieselene in a duel-fuel system, also to obtain a somewhat better output than would be achieved by normal diesel

operation. In fact, higher outputs were obtained, but there was a small increase in smoke emission. If the dieselene is reduced slightly, however, it should be possible to achieve the output of the normal diesel engine and not exceed the acceptable smoke emission level (Bosch No. 4).

(ii) A higher output is possible using an alcohol-enriched dual-fuel engine than with a petrol enriched one.

(iii) Considering the fuel consumption over the whole speed range of the engine, the normal diesel engine is the highest, the ethyl alcohol-enriched engine is in the middle and the petrol-enriched engine is the lowest.

(iv) From the standpoint of efficiency, both the petrol-enriched and alcohol-enriched engines have efficiencies of the order of 30%, whilst the figure for the normal diesel engine at the same output is of the order of 25%.

(v) In order to stay within permitted smoke emission standards, a dieselene pump stop setting of 7,5 mm was used for petrol addition. This measurement could, however, be increased to 8,5 mm when ethyl alcohol was used. It is thus concluded that ethyl alcohol has a degree of smoke reducing effect.

(vi) The maximum permissible jet size for ethyl alcohol was 90, with the 100 jet the engine missed badly. Hence, the fuel flow had to be reduced by the use of a leaner needle setting. This was caused by the higher latent heat.

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PRETORIA
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TABLE 1

Properties of	Ethyl alcohol	Methyl alcohol	Petrol	Dieselene
	C2H5OH	CH3OH	CH	CH
Specific gravity kg/l	0,80	0,80	0,67 - 0,75	0,84 - 0,92
Composition %	C H O 52 13 35	C H O 38 12 50	C H 81 15	C H 86 13
Freezing point ^{o}C	-114	-98	-30 to -50	-25 to 0
Boiling point ^{o}C	+78,5	+65	Average 120 40 - 200	270 - 400
Latent heat kcal/kg	225	262	90 - 120	-
Calorific value (lower) kcal/kg	6500	4700	9800	8200 - 9200
Self ignition ^{o}C	400 - 460	470	550	350
Air/fuel ratio kg/kg	9:1	6,5:1	13,8:1	15:1
Ignition boundaries lower	2,6 - 4	4 - 7,8	0,7 - 2,4	-
Ignition boundaries upper	9 - 19	14 - 36	4,3 - 6	-
Octane value	106	112	Regular 87 Super 93	-
Cetane value	-	-	-	50

TABLE 2
RESULTS OF PRELIMINARY TESTS

TEST NO. 1. 7,5 mm derated diesel engine - 75 jet secondary fuel -3,0 needle position
USED FOR INITIAL TORQUE INDICATIONS

TEST NO. 2. 7,5 mm derated diesel engine - 75 jet secondary fuel - 2,0 to 4,0 needle position
SEARCH FOR OPTIMUM NEEDLE POSITION

TEST NO. 3. 7,5 mm derated diesel engine - 75 jet secondary fuel - 3,0 needle position
TORQUE CHECKED OVER FULL SPEED RANGE

TEST NO. 4. 7,5 mm derated diesel engine - 90 jet secondary fuel - 3,0 needle position
SEARCH FOR OPTIMUM JET SIZE

TEST NO. 5. 7,5 mm derated diesel engine - 90 jet secondary fuel - 2,0 to 4,0 needle position
SEARCH FOR OPTIMUM NEEDLE POSITION

TEST NO. 6. 8,5 mm derated diesel engine - 90 jet secondary fuel - 3,0 needle position
CHECK ON OPTIMUM DIESELENE SUPPLY FOR POWER AND SMOKE

TEST NO. 7. 8,5 mm derated diesel engine - 90 jet secondary fuel - 2,0 to 4,0 needle position
SEARCH FOR OPTIMUM NEEDLE POSITION

TABLE 3

Test No.	Primary Fuel	Secondary Fuel	Pump Stop m.m.	Jet Size	Needle Position	RPM	Output (KW)	Torque P	Torque Nm	Consumpt. Dieselene (Kg/min)	Consumpt. Secondary (Kg/min)	Consumpt. Total (g/KWh)	Air (Kg/min)	Smoke Bosch No	Remarks
1E 23.6.77	Shell dieselene	Ethyl alcohol	7,5	75	3,0	1083	23,2	21,4	204,6	0,061	0,050	287	1,81	2,3	First attempt; the jet was too small for good output; but almost no smoke.
						1539	30,9	20,1	192,2	0,092	0,051	276	2,56	2,2	
						2046	40,3	19,7	188,3	0,130	0,058	279	3,25	2,7	
						2571	40,1	15,6	149,1	0,150	0,051	301	3,96	1,4	
2E 24.6.77	Shell dieselene	Ethyl alcohol	7,5	75	3,0	1079	22,4	20,8	198,9	0,061	0,049	295	1,84	2,1	Repeat of test No. 1 Results similar
						1555	31,4	20,2	193,1	0,092	0,053	277	2,55	1,8	
						2065	40,3	19,5	186,4	0,131	0,061	287	3,34	2,6	
						2593	41,0	15,8	151,1	0,151	0,052	296	3,99	1,7	
3E 24.6.77	Shell dieselene	Ethyl alchol	7,5	75	2,5	1044	20,3	19,4	185,5	0,055	0,035	271	1,73	1,6	Ethyl alcohol flow reduced by needle - output reduced.
						1511	29,8	19,7	188,3	0,090	0,038	258	2,45	3,0	
						2099	39,5	18,8	179,7	0,132	0,043	265	3,29	1,9	
						2568	38,5	15,0	143,4	0,148	0,044	299	3,90	2,1	
4E 24.6.77	Shell dieselene	Ethyl alcohol	7,5	90	2,5	1093	21,4	19,6	187,4	0,061	0,038	275	1,81	2,1	Ethyl alcohol jet size increased; but flow restricted to that of previous test.
						1503	28,5	19,0	181,6	0,088	0,036	259	2,43	1,9	
						2020	37,6	18,5	177,8	0,128	0,041	271	3,17	3,0	
						2522	37,8	15,0	143,4	0,144	0,040	292	3,81	1,6	
5E 12.7.77	Shell dieselene	Ethyl alcohol	7,5	90	2,9	1076	21,3	19,8	189,3	0,063	0,039	286	1,79	2,1	Despite increased needle setting no increase in power; thought to be due to a fault in the ethyl alcohol flow system. The electric fuel pumps were checked and replaced, but problem not solved.
						1565	30,2	19,3	184,5	0,097	0,045	282	2,57	2,1	
						2060	37,5	18,2	174,0	0,132	0,044	281	3,29	2,4	
						2570	37,3	14,5	138,6	0,152	0,042	311	3,90	1,2	
6E 17.8.77	Shell dieselene	Ethyl alcohol	8,5	90	2,5	1083	20,0	18,5	176,9	0,072	0,020	277	1,81	3,0	Dieselene setting was bigger. At 1083 rpm the torque was too high for the dynamometer, therefore only a 2,5 needle setting could be used. All the other revolutions used a 3,0 needle setting with a good output.
					3,0	1551	32,9	21,2	202,7	0,110	0,049	289	2,47	3,8	
						2080	42,0	20,2	193,1	0,148	0,063	301	3,18	4,2	
						2635	41,6	15,8	151,1	0,170	0,054	322	3,87	2,6	
7E 24.8.77	Shell dieselene	Ethyl alcohol	8,5	100	2,6	1089	21,8	20,0	191,2	0,074	0,029	283	1,86	3,0	This test could not be run with a needle setting of 3,0 because the engine was missing badly. Ethyl alcohol supply was too high causing compressed air cooling.
						1549	29,9	19,3	184,5	0,111	0,028	278	2,58	3,3	
						2062	38,3	18,8	177,8	0,148	0,033	285	3,31	3,7	
						2532	39,0	15,4	147,2	0,166	0,031	302	3,98	3,4	

TABLE 4

Test No.	Primary Fuel	Secondary Fuel	Pump Stop m.m.	Jet Size	Needle Position	RPM	Output (KW)	Torque (P)	Torque (Nm)	Consumpt. Dieselene (Kg/min)	Consumpt. Secondary (Kg/min)	Consumpt. Total (g/KWh)	Air (Kg/min)	Smoke Bosch No.	Air; Fuel Ratio	Brake Efficiency (%)
9D 18.10.77	Shell dieselene	None	7,5	-	-	1074	14,0	13,0	124,3	0,060	-	255	1,82	1,6	30,6	30,9
						1591	22,1	13,9	132,9	0,097	-	263	2,59	1,6	26,7	30,9
						2061	28,8	14,0	133,8	0,127	- -	263	3,21	1,6	25,4	29,9
						2551	30,6	12,0	114,7	0,148	-	291	3,90	1,4	26,3	27,1
8D 17.10.77	Shell dieselene	None	8,5	-	-	1059	16,4	15,5	148,2	0,073	-	269	1,69	3,7	23,0	29,3
						1569	25,9	16,5	157,7	0,116	-	268	2,46	4,0	21,3	29,4
						2092	33,9	16,2	154,9	0,154	-	273	3,25	4,4	21,1	28,9
						2576	35,5	13,8	131,9	0,173	-	293	4,10	3,1	23,7	27,0
10D 18.10.77	Shell dieselene	None	11,4	-	-	1107	21,9	19,8	189,3	0,114	-	312	1,76	8,9	15,4	25,3
						1557	30,5	19,6	187,4	0,159	-	314	2,39	8,4	15,0	25,2
						2079	38,5	18,5	176,9	0,208	-	324	3,08	8,0	14,8	24,4
						2562	41,2	16,1	153,9	0,221	-	322	3,73	6,7	16,8	24,4
11E 18.10.77	Shell dieselene	Ethyl alcohol	8,5	90	3,0	1085	24,1	22,2	212,2	0,073	0,045	295	1,74	4,2	14,7	31,2
						1557	32,5	20,9	199,8	0,112	0,045	289	2,41	4,8	15,4	30,5
						2053	39,6	19,3	184,5	0,148	0,049	298	3,08	4,7	15,6	29,1
						2538	42,1	16,6	158,7	0,167	0,053	312	3,72	3,6	16,9	27,7
1P 17.6.77	Shell dieselene	Mobil Premium Petrol	7,5	37	2,5	1092	21,8	20,0	191,2	0,062	0,031	256	1,82	3,4	19,5	30,7
						1520	29,9	19,7	188,3	0,091	0,034	250	2,50	3,0	20,0	31,4
						2052	38,0	18,5	172,1	0,131	0,035	262	3,28	3,2	19,8	30,0
						2526	40,2	15,9	152,0	0,147	0,036	274	3,89	2,2	21,2	28,7

TABLE 5.

Test No. 1P carb. VI of 17.6.77

Lower ignition boundary for Mobil Premium - 1,6%

RPM	Petrol (kg/min)	Air (kg/min)	% of petrol (weight)
1092	0,031	1,82	1,70
1276	0,032	2,08	1,50
1520	0,034	2,50	1,36
1832	0,034	2,97	1,14
2052	0,035	3,28	1,06
2314	0,036	3,64	0,99
2526	0,036	3,89	0,93

Test No. 1 carb. VI Dual-Fuel Operation Air: Fuel Ratio			Normal Diesel Operation Test No. 10D of 18.10.77		
RPM	Total	λ	RPM	Air: Fuel Ratio	λ
1092	19,5	1,3	1107	15,4	1,03
1276	19,3	1,29	1300	15,0	1,0
1520	20,0	1,33	1557	15,0	1,0
1832	19,6	1,31	1818	15,0	1,0
2052	19,8	1,32	2079	14,8	0,99
2314	20,4	1,36	2328	15,2	1,01
2526	21,2	1,41	2562	16,8	1,12

Comparison of total fuel consumption

Test No. 10D of 18.10.77 Normal Diesel Operation 11,4 mm pump stop			Test No. 1 carb. VI of 6.6.77 Dual-Fuel Operation			Fuel Saving	
RPM	Fuel consumption (g/KWh)	Brake Efficiency	RPM	Total Consumption	Efficiency %	g/KWh	%
1107	312	25,3	1092	256	30,7	56	17,9
1300	316	24,9	1276	255	30,8	61	19,3
1557	314	25,2	1520	250	31,4	64	20,4
1818	320	24,7	1832	257	30,6	63	19,7
2079	324	24,4	2052	262	30,0	62	19,1
2328	329	24,0	2314	269	29,2	60	18,2
2562	322	24,4	2526	274	28,7	48	14,9

Comparison of smoke level

Normal Diesel Operation Test No. 10D of 18.10.77		Dual-Fuel Operation Test No. 1 carb. VI of 17.6.77		Smoke Decrease	
RPM	Smoke No.	RPM	Smoke No.	No.	%
1107	8,9 = 100%	1092	3,4	5,5	61,8
1300	8,4	1276	3,5	4,9	58,3
1557	8,4	1520	3,0	5,4	64,3
1818	8,2	1832	3,6	4,6	56,1
2079	8,0	2052	3,2	4,8	60,0
2328	7,6	2314	3,1	4,5	59,2
2562	6,7	2526	2,2	4,5	67,2

Comparison of exhaust temperatures

Normal Diesel operation Test No. 10D of 18.10.77		Dual-Fuel Operation Test No. 1 carb. VI of 17.6.77		Temperature Decrease °C
RPM	Temp. °C	RPM	Temp. °C	
1107	460	1092	430	30
1300	495	1276	440	55
1557	560	1520	460	100
1818	625	1832	500	125
2079	680	2052	530	150
2328	720	2314	555	165
2562	720	2526	560	160

Ratio: Dieselene: Petrol

Test No. 1 carb. VI of 17.6.77

Rpm	dieselene kg/min	petrol kg/min	Ratio	% petrol to dieselene
1092	0,062	0,031	2,0	50,0
1276	0,076	0,032	2,38	42,1
1520	0,091	0,034	2,68	37,4
1832	0,117	0,034	3,34	29,1
2052	0,131	0,035	3,64	26,7
2314	0,142	0,036	3,94	25,3
2526	0,147	0,036	4,08	24,5

TABLE 5 (contd)

COMPARISON OF OUTPUT

Normal diesel operation Test No. 100 - 18/10/77		Dual-fuel operation Test No. 1 carb. VI - 17/6/77		Decrease of output
R.p.m.	KW	R.p.m.	KW	KW
1107	21,9	1092	21,8	0,1
1300	25,5	1276	25,4	0,1
1557	30,5	1520	29,9	0,6
1818	34,7	1832	35,5	-0,8 (i.e. increase)
2079	38,5	2052	38,0	0,5
2328	40,5	2314	39,8	0,7
2562	41,2	2526	40,2	1,0

TABLE 6

Test No. 11 D + E of 17.6.77

Lower ignition boundary for ethyl alcohol 2,6 - 4% in air (vol %)

RPM	Ethyl alcohol (Kg/min)	Air (Kg/min)	% of ethyl alcohol (by weight)
1085	0,045	1,74	2,59
1290	0,043	1,99	2,16
1557	0,045	2,41	1,87
1820	0,047	2,79	1,68
2053	0,049	3,08	1,59
2314	0,051	3,34	1,53
2538	0,053	3,72	1,42

Normal Diesel Operation Test No. 10D of 18.10.77			Dual Fuel Operation Test No. 11 carb. VI of 18.10.77		
RPM	Air: Fuel Ratio	λ	RPM	Air: Fuel Ratio (Total)	λ
1107	15,4	1,03	1085	14,7	0,98
1300	15,0	1,0	1290	14,7	0,98
1557	15,0	1,0	1557	15,4	1,03
1818	15,0	1,0	1820	15,6	1,04
2079	14,8	0,99	2053	15,6	1,04
2328	15,2	1,01	2314	15,7	1,05
2562	16,8	1,12	2538	16,9	1,10

Comparison of total fuel consumption

Test No. 10D of 18.10.77 Normal Diesel Operation			Test No. 11 carb. VI of 18.10.77 Dual Fuel Operation			Fuel Saving	
RPM	Fuel Consumption	Brake Efficiency	RPM	Total : Consumption	Efficiency	(g/KWh)	%
1107	312 g/KWh	25,3%	1085	295	31,2%	17	5,4
1300	316	24,9	1290	295	30,4	21	6,6
1557	314	25,2	1557	289	30,5	25	8,0
1818	320	24,7	1820	292	29,9	28	8,8
2079	324	24,4	2053	298	29,1	26	8,0
2328	329	24,0	2314	301	28,7	28	8,5
2562	322	24,4	2538	312	27,7	10	3,1

Comparison of smoke level

Normal Diesel Test No. 10D of 18.10.77		Dual Fuel Operation Test No. 11 of 18.10.77		Smoke Decrease	
RPM	Smoke No.	RPM	Smoke No.	No.	%
1107	8,9 = 100%	1085	4,2	4,7	58,8
1300	8,4	1290	4,6	3,8	45,2
1557	8,4	1557	4,8	3,6	42,9
1818	8,2	1820	4,7	3,5	42,7
2079	8,0	2053	4,7	3,3	41,3
2328	7,6	2314	4,4	3,2	42,1
2562	6,7	2538	3,6	3,1	46,3

Comparison of exhaust temperatures

Normal Diesel Test No. 10D of 18.10.77		Dual Fuel Operation Test No. 11 of 18.10.77		Temperature Difference
RPM	Exhaust Temperature (°C)	RPM	Exhaust Temperature (°C)	°C
1107	460	1085	485	+25
1300	495	1290	500	+ 5
1557	560	1557	540	-40
1818	625	1820	580	-45
2079	680	2053	620	-60
2323	720	2314	640	-80
2562	720	2538	655	-65

Ratio: Dieselene: Petrol

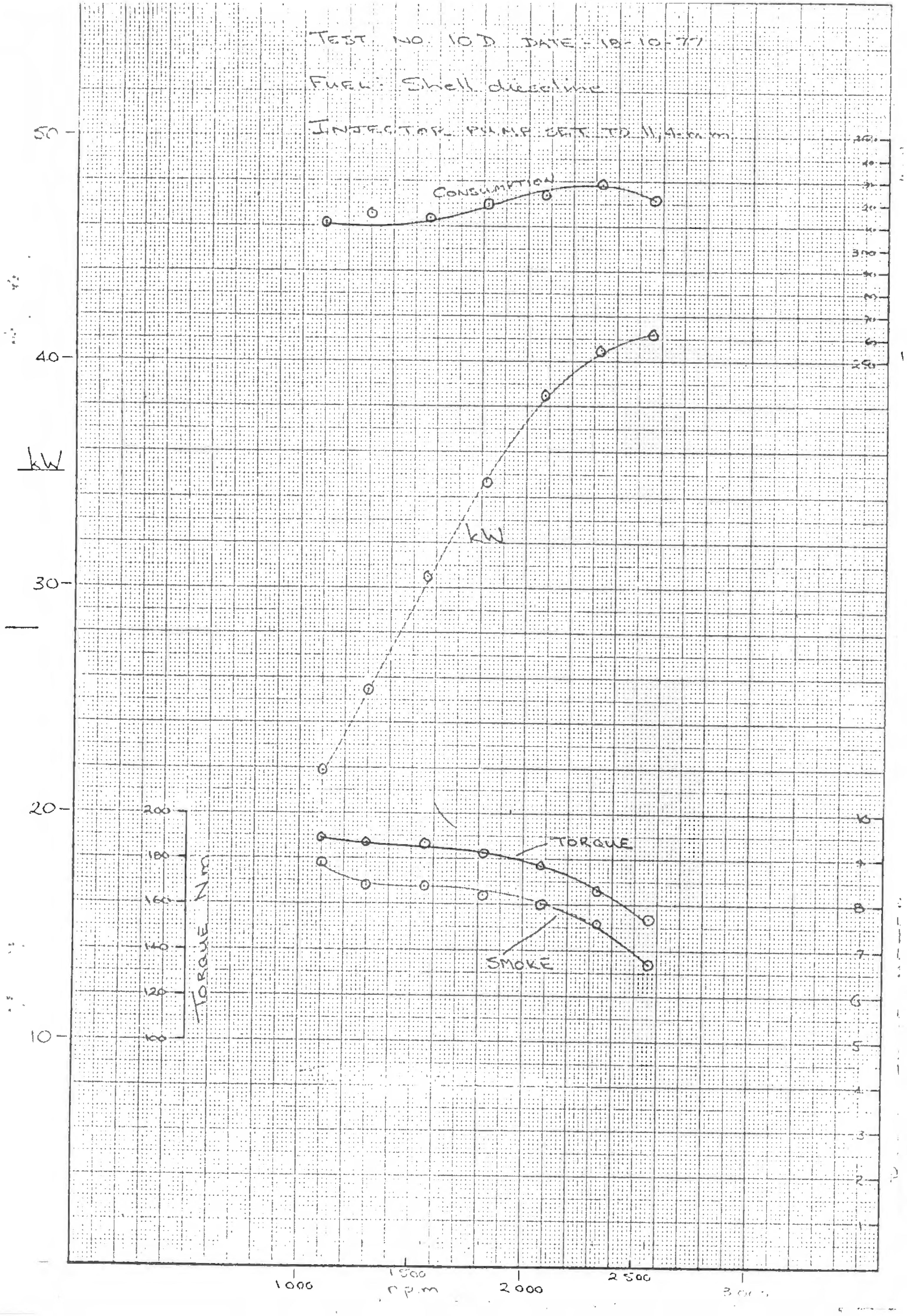
Test No. 11 of 18.10.77

RPM	Dieselene (Kg/min)	Petrol (kg/min)	Ratio	% Petrol
1085	0,073	0,045	1,6	61,6
1290	0,092	0,043	2,1	46,7
1557	0,112	0,045	2,5	40,2
1820	0,132	0,047	2,8	35,6
2053	0,148	0,049	3,0	33,1
2314	0,162	0,051	3,2	31,5
2538	0,167	0,053	3,2	31,7

TABLE 6 (contd)

COMPARISON OF OUTPUT

Normal diesel operation Test No. 10D - 18/10/77		Dual-fuel operation Test No. 11D + E - 18/10/77		Increase of output
R.p.m.	KW	R.p.m.	KW	KW
1107	21,9	1085	24,1	2,2
1300	25,5	1290	27,5	2,0
1557	30,5	1557	32,5	2,0
1818	34,7	1820	36,8	2,1
2079	38,5	2053	39,6	1,1
2328	40,5	2314	42,4	1,9
2562	41,2	2538	42,1	0,9



TEST NO 10D DATE 18-10-77
FUEL: Shell dieselime
CONSUMPTION
kW
TORQUE
SMOKE
TORQUE Nm
r.p.m
1000
2000
2500
50
40
30
20
10
200
180
160
140
120
100

BENCH TEST RESULTS TEST NO. 10D DATE: 18/10/77

Engine: Ford diesel Vol. Vo. 3611 cm^3 **Fuel:** Shell dieselene Gross C.V.: 45640 KJ/kg

11,4 mm Pump stop

Actual speed r.p.m.	Air rate m^3/min.	Air rate kg/min.	Fuel rate kg/min.	A/F Ratio	Input kW	Torque N.m.	Torque p	Output kW	Efficiency Brake %	Efficiency Volume %	Consump gr/KWh	Bosch smoke
n	Va	1,015 Ma	0,834 M	α	45640 Q	T	p	L	η	τ	υ	No.
1107	1,73	1,76	0,114	15,4	86,7	189,3	19,8	21,9	25,3	86,5	312	8,9
1300	1,99	2,02	0,135	15,0	102,5	187,4	19,6	25,5	24,9	84,8	316	8,4
1557	2,35	2,39	0,159	15,0	121,2	187,4	19,6	30,5	25,2	83,6	314	8,4
1818	2,73	2,77	0,185	15,0	140,7	182,6	19,1	34,7	24,7	83,1	320	8,2
2079	3,03	3,08	0,208	14,6	157,9	176,9	18,5	38,5	24,4	80,7	324	8,0
2328	3,32	3,37	0,222	15,2	168,8	166,3	17,4	40,5	24,0	79,0	329	7,6
2562	3,67	3,73	0,221	16,8	168,4	153,9	16,1	41,2	24,4	79,3	322	6,7

Air rate Va and Ma in first instance from $V = k\sqrt{\Delta P}$ (when $\Delta p >$ 2 mm H_2O).

This is correct for air density $p = 1$ kg/m^3. Density correction Va = V:

$\sqrt{p}$ Ma = $V\sqrt{p}$, Q = M.CV, L = $p.n.10^{-3}$, = Ma/M, = 100.L/Q, = 200.Va/n.Vo,

$n = \frac{N}{t}$

d = 75,4 mm	k = 0,88
67,9	0,68
60,7	0,51

BENCH TEST RECORD   TEST NO. 10D carb. VI   DATE: 18/10/77

Engine: Ford diesel   Fuel: Shell dieselene

Auxiliaries used: Airfilter/Air tank/Fan/Generator   Barometer 656

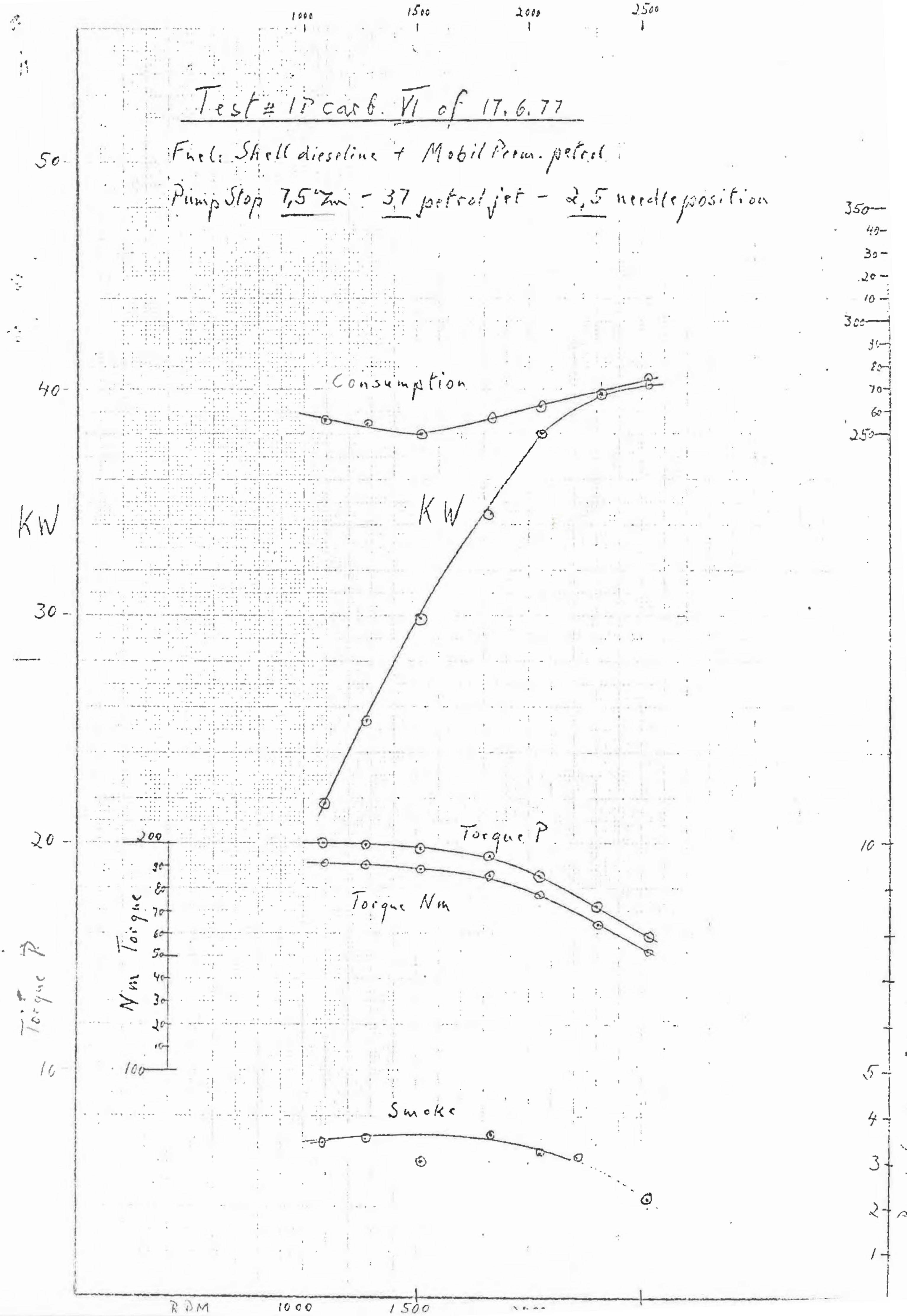
Ignition or injection timing: 22°BTDC (Static)   Humidity 54

Compression ratio: 16:1

Other remarks on engine adjustments: 11,4 mm Pump stop

Air orifice dia: 75,4 mm   Measuring vessel: 200 cm^3 (grams)

Speed (Tacho)	Torque		Power (Meter)	Consumption		Temperatures			Fuel	Pressures	Smoke Bosch No.
r.p.m.	Nm	P	Kw	Time S	Revs. No.	Amb. °C	Exh. °C	Water		Diff. mmH_2O	
n^1	T	p	L^1	t	N	ta	te	tw	°C	Δp	
1107	189,3	19,8	21,9	67,8	1620		460	47		3,8	8,9
1300	187,4	19,6	25,5	74,3	1610		495	48		5,1	8,4
1557	187,4	19,6	30,5	62,8	1630	25,8	560	49	22,6	7,0	8,4
1818	182,6	19,1	34,7	54,1	1640		625	51		9,4	8,2
2079	176,9	18,5	38,5	48,2	1670		680	52		11,6	8,0
2328	166,3	17,4	40,5	45,1	1750		720	54		13,9	7,6
2562	153,9	16,1	41,2	45,2	1930		720	55		16,8	6,7


Test # 17 carb. VI of 17.6.77
Fuel: Shell dieseline + Mobil Prem. petrol
Pump Stop 7,5°Zm - 37 petrol jet - 2,5 needle position
Consumption
KW
Torque P
Torque Nm
Smoke
Nm Torque
Torque P
KW
RPM
1000
1500
2000
2500
50
40
30
20
10
200
100
350
300
250

BENCH TEST RESULTS   TEST NO. 1 carb. VI   DATE: 17/6/77

Engine: Ford diesel   Vol. Vo. 3611 cm^3 Fuel: Shell dieselene   Gross C.V.: 45640 KJ/kg

7,5 mm Pump stop - 37 jet - 2½ needle position   Mobil Prem. petrol   46500 KJ/kg

Actual speed r.p.m.	Air rate		Fuel rate		A/F Ratio		Input		Torque		Out-put	Efficiency		Total				Smoke
	m^3/ min.	kg/ min.	kg/min.				kW		N.m.	p	kW	Brake %	Vo-lume %	gr/ KWh	Input	Air: Fuel ratio	Fuel rate	
n	Va	1,05 Ma	D 0,840 (M)	P 0,715	D (α)	P	D 45640 (Q)	P 46500	T	p	L	η	τ	υ			kg/ min.	Bosch No.
1092	1,73	1,82	0,062	0,031	29,1	59,2	47,4	23,8	191,2	20,0	21,8	30,7	87,8	253	71,2	19,5	0,093	3,4
1276	1,98	2,08	0,076	0,032	27,3	65,6	57,8	24,6	190,2	19,9	25,4	30,8	85,9	255	82,4	19,3	0,108	3,5
1520	2,38	2,50	0,091	0,034	27,5	74,0	69,1	26,2	188,3	19,7	29,9	31,4	86,7	250	95,3	20,0	0,125	3,0
1832	2,83	2,97	0,117	0,034	25,3	86,1	89,4	26,7	176,8	19,4	35,5	30,6	85,6	257	116,1	19,6	0,152	3,6
2052	3,12	3,28	0,131	0,035	25,1	92,9	99,3	27,3	172.1	18,5	38,0	30,0	84,2	262	126,7	19,8	0,166	3,2
2314	3,47	3,64	0,142	0,036	25,6	101,4	108,3	27,8	164,4	17,2	39,8	29,2	83,1	263	136,1	20,4	0,178	3,1
2526	3,70	3,89	0,147	0,036	26,4	108,7	112,1	27,7	152,0	15,9	40,2	28.7	81,1	274	139,8	21,2	0,183	2,2

Air rate Va and Ma in first instance from $V = k\sqrt{\Delta p}$ (when $\Delta p >$ 2 mm H_2O).

This is correct for air density $\rho = 1$ kg/m^3. Density correction Va = V:

$\sqrt{\rho}$ Ma = V$\sqrt{\rho}$, Q = M.CV, L = $p.n.10^{-3}$, = Ma/M, = 100.L/Q, = 200.Va/n.Vo,

$n = \frac{N}{t}$

d	k
d = 75,4 mm	k = 0,88
67,9	0,68
60,7	0,51

BENCH TEST RECORD TEST NO. 1 carb. VI DATE: 16/6/77

Engine: Ford diesel Fuel: Shell dieselene + Mobil prem. petrol

Auxiliaries used: Airfilter/Air tank/Fan/Generator Barometer 661

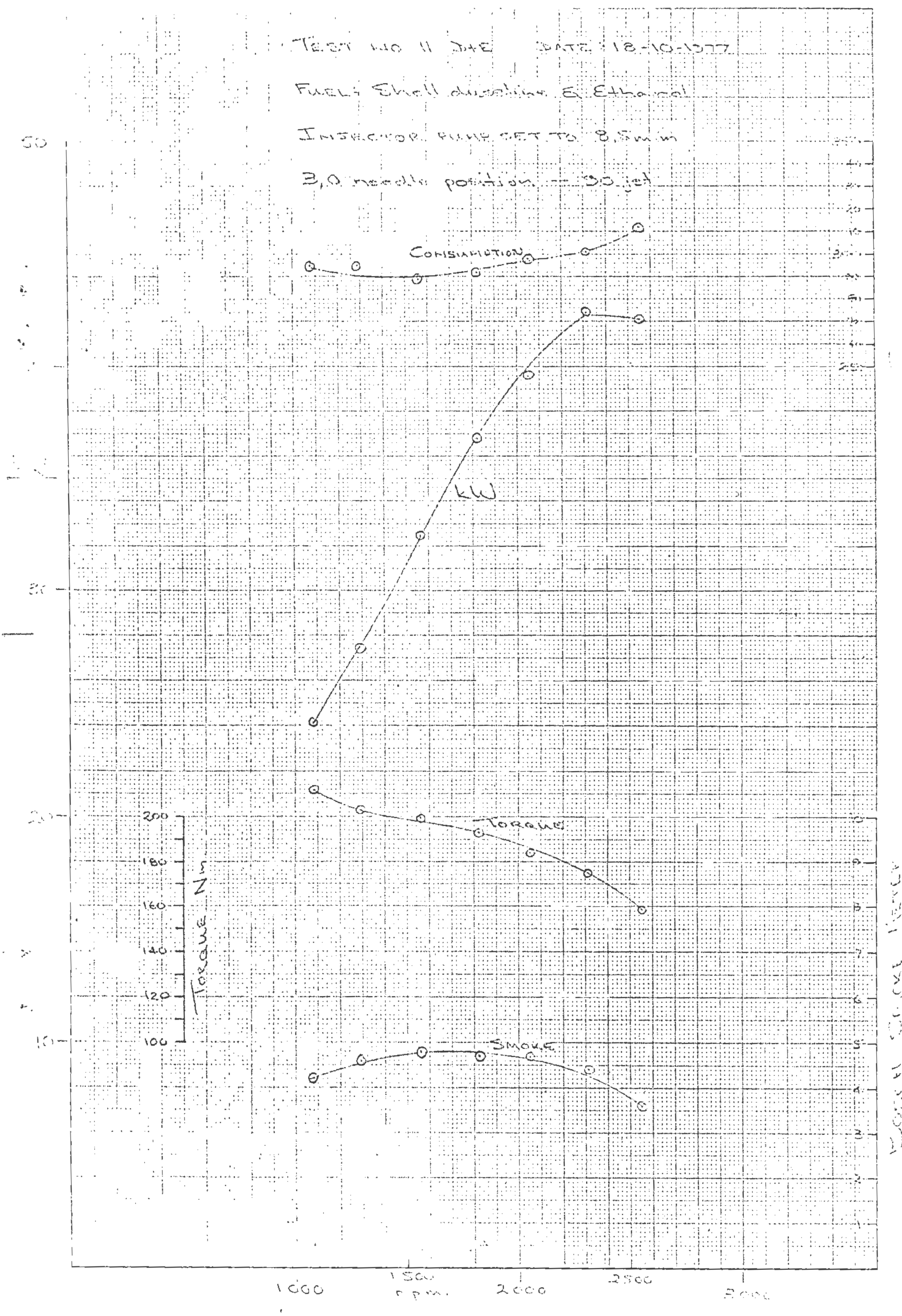
Ignition or injection timing: 22^{o}BTDC (static) Humidity 46,5

Compression ratio: 16:1

Other remarks on engine adjustments: 7,5 mm pump stop - 37 jet - 2½ needle position - el. feed pump

Air orifice dia. 75,4 mm Measuring vessel: 200 cm^3 (grams)

Speed (Tacho)	Torque		Power (meter)	Consumption		Temperatures			Fuel	Pressures	Smoke Bosch	Petrol consumption time
r.p.m.	Nm	p	Kw	Time S	Revs. No.	Amb. ^oC	Exh. ^oC	Water		Diff. mmH_2O	No.	
n^1	T	p	L^1	t	N	ta	te	tw		Δp		sec
1092	191,2	20,0	21,8	161,6	2940		430	44		3,8	3,4	287,5
1276	190,2	19,9	25,4	132,6	2820		440	44		5,0	3,5	278,3
1520	186,3	19,7	29,9	110,9	2810	20,0	460	45	17,8	7,2	3,0	261,3
1832	185,5	19,4	35,5	85,8	2620		500	50		10,2	3,6	255,8
2052	176,8	18,5	36,0	77,2	2640		530	54		12,4	3,2	250,0
2314	164,4	17,2	39,8	70,8	2730		555	58		15,2	3,1	245,5
2526	152,0	15,9	40,2	68,4	2680		560	61		17,2	2,2	246,7


TEST NO 11 D+E DATE: 18-10-1977
FUEL: Shell diesoline & Ethanol
INJECTOR PUMP SET TO 8,5mm
3,0 needle position — 90 jet
CONSUMPTION
kW
TORQUE
SMOKE
TORQUE Nm
200
180
160
140
120
100
50
20
10
1000
1500
2000
2500
3000
rpm

BENCH TEST RESULTS TEST NO. 11 D + E DATE: 18/10/77

Engine: Ford diesel Vol. Vo. 3611 cm^3 Fuel: Shell dieselene Gross C.V. 45640 KJ/kg

8,5 mm Pump stop - 90 jet - 3,0 needle position + ethanol 28840 KJ/kg

Actual speed r.p.m.	Air rate m³/min.	Air rate kg/min.	Fuel rate kg/min.		A/F Ratio		Input kW		Torque N.m.	p	Ouput kW	Efficiency Brake %	Efficiency Volume %	Total con-sumpt. gr/KWh	Bosch smoke	Total Input kW	Total Air: Fuel ratio	Total Fuel rates kg/min.	Bosch smoke
		1,005	0,831	0,705			45640	28840											
n	Va	Ma	M D	M E	α		Q		T	p	L	η	τ	υ	No.				No.
1085	1,73	1,74	0,073	0,045	23,8	38,4	55,5	21,7	212,2	22,2	24,1	31,2	88,3	295	4,2	77,3	14,7	0,118	4,2
1290	1,98	1,99	0,092	0,043	21,7	46,0	69,7	20,8	203,6	21,3	27,5	30,4	85,0	295	4,6	90,5	14,7	0,135	4,6
1557	2,40	2,41	0,112	0,045	21,6	53,1	84,8	21,9	199,8	20,9	32,5	30,5	85,4	289	4,8	106,7	15,4	0,157	4,8
1820	2,78	2,79	0,132	0,047	21,2	59,8	100,5	22,5	193,1	20,2	36,8	29,9	84,6	292	4,7	122,9	15,6	0,179	4,7
2053	3,06	3,08	0,148	0,049	20,7	63,1	112,9	23,4	184,5	19,3	39,6	29,1	82,5	298	4,7	136,3	15,6	0,197	4,7
2314	3,32	3,34	0,162	0,051	20,6	65,7	122,9	24,4	175,0	18,3	42,4	28,7	79,5	301	4,4	147,3	15,7	0,212	4,4
2536	3,70	3,72	0,167	0,053	22,3	70,7	126,8	25,3	158,7	16,6	42,1	27,7	80,7	312	3,6	152,1	16,9	0,219	3,6

Air rate Va and Ma in first instance from $V = k\sqrt{\Delta p}$ (when $\Delta p > 2$ mm H_2O).
This is correct for air density $\rho = 1$ kg/m^3. Density correction Va = V:
$\sqrt{\rho}$ Ma = $V\sqrt{\rho}$, Q = M.CV, L = p.n. 10^{-3}, = Ma/m, = 100.L/Q, = 200.Va/n.Vo,
$n = \frac{N}{t}$

d	k
d = 75,4 mm.	k = 0,88
67,9	0,68
60,7	0,51

BENCH TEST RECORD   TEST NO. 11 D + E carb. VI   DATE: 18/10/77

Engine: Ford diesel   Fuel: Shell dieselene + Ethanol

Auxiliaries used: Airfilter/Air tank/Fan/Generator   Barometer 654

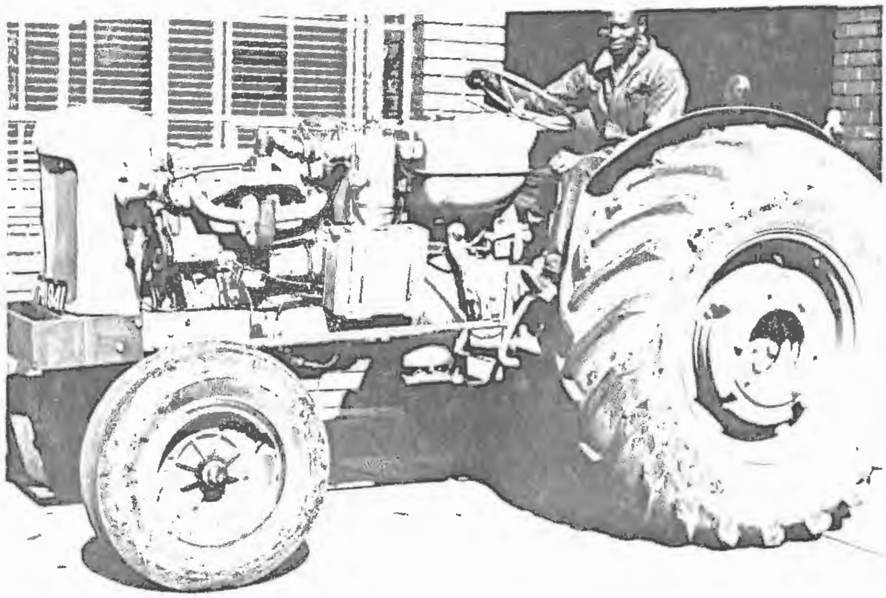
Ignition or injection timing: 22^{o}BTDC (static)   Humidity 40

Compression ratio: 16:1

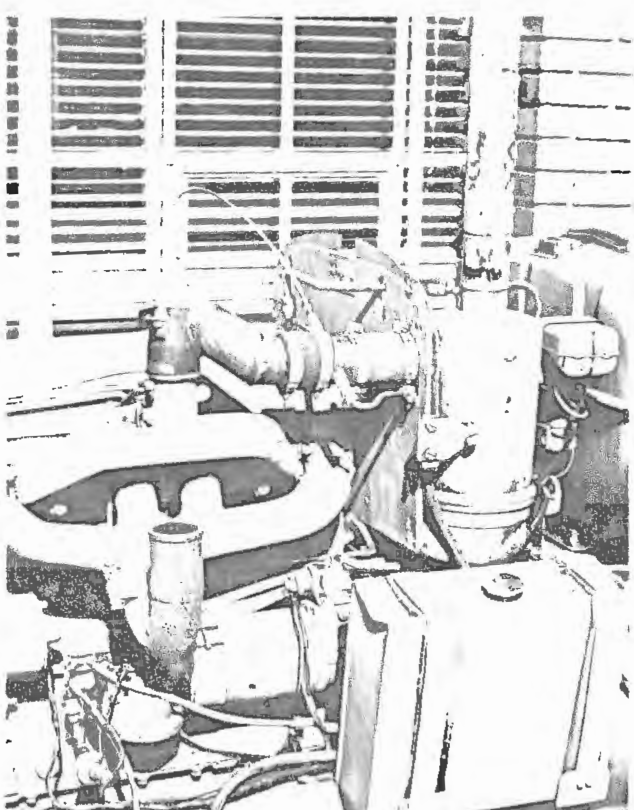
Other remarks on engine adjustments: 8,5 mm Pump stop - 90 jet - 3,0 needle position

Air orifice dia. 75,4 mm   Measuring vessel: 200 cm^3 (grams)

Speed (Tacho) r.p.m.	Torque Nm	Torque p	Power (meter) Kw	Consumption Time S	Consumption Revs. No.	Temperatures Amb. °C	Temperatures Exh. °C	Temperatures Water	Fuel	Pressures Diff. mmH_2O	Smoke Bosch No.	Consumpt. time Ethanol
n^1	T	p	L^1	t	N	ta	te	tw	°C	Δp		sec.
1085	212,2	22,2	24,1	136,3	2470		485	55		3,8	4,2	208,2
1290	203,6	21,3	27,5	108,8	2340		500	54		5,0	4,6	217,7
1557	199,8	20,9	32,5	89,4	2320	29,0	540	57	26,4	7,3	4,8	207,2
1820	193,1	20,2	36,8	75,5	2290		580	59		3,8	4,7	201,5
2053	184,5	19,3	39,6	67,2	2300		620	61		11,8	4,7	193,2
2314	175,0	18,3	42,4	61,7	2380		640	64		13,9	4,4	185,6
2538	158,7	16,6	42,1	59,8	2530		655	66		17,2	3,6	179,0



Tractor altered for dual-fuel operation.



Details of the alterations suitable for petrol, ethyl alcohol or methyl alcohol as secondary fuel.

KEY

⊙ Dieseline derated operation-pump stop 7,5 m.m.

⊡ Dieseliné normal operation-pump stop 11,4 m.m.

× Dieseline + petrol operation-pump stop 7,5 m.m. - 35 jet - 2,5 needle setting

△ Dieseline + ethyl alcohol operation-pump stop 7,5 m.m. - 35 jet - 3,0 needle setting

⊗ Dieseline + ethyl alcohol operation-pump stop 8,5 m.m. - 90 jet - 3,0 needle setting

✱ Dieseline + ethyl alcohol operation-pump stop 8,5 m.m. - 100 jet - 2,6 needle setting

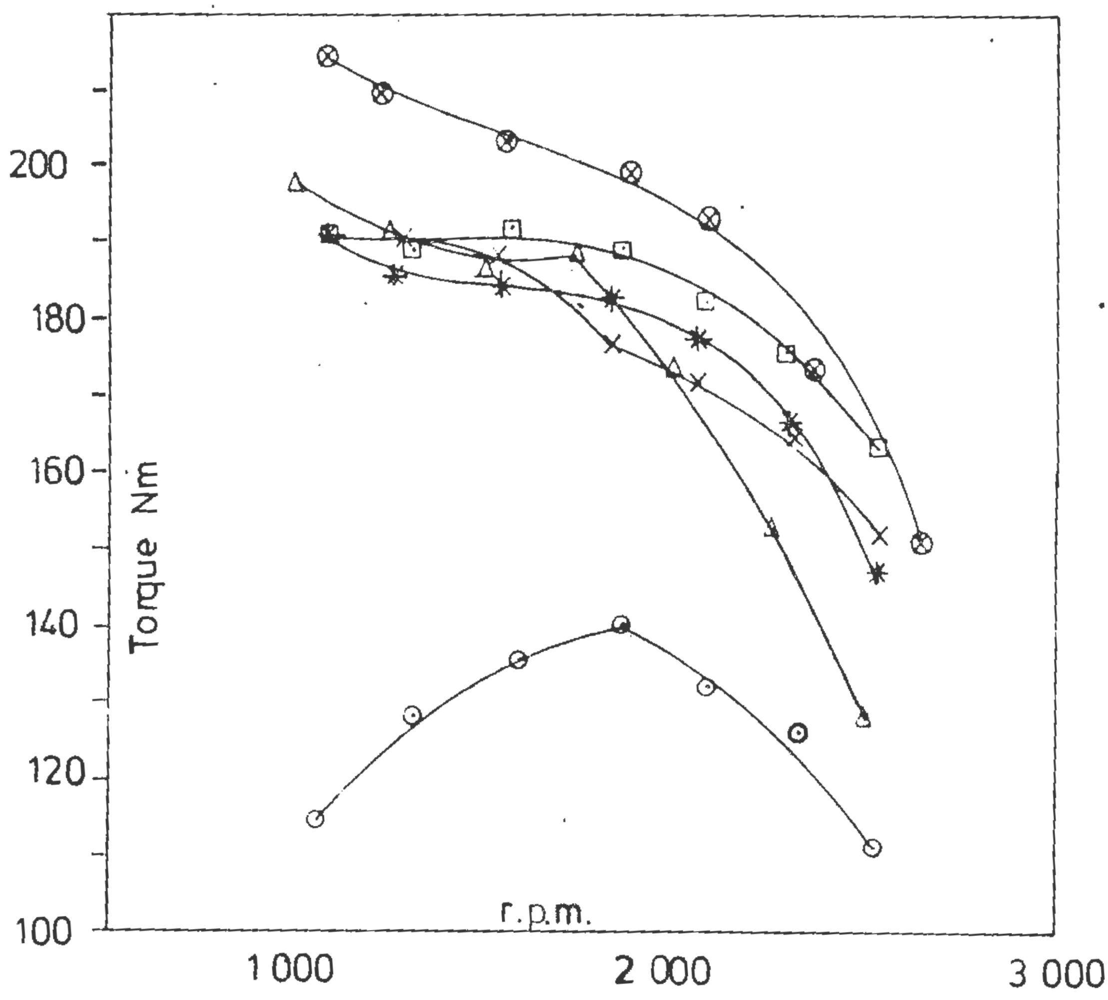


Figure 1 TORQUE COMPARISON