Preliminary emissions analysis of a methanol/dimethyl ether fuelled compression ignition engine

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A great deal of research has been conducted using methanol as an alternative fuel. With increasingly stringent emission legislation in Europe, the United States and Japan, researchers dedicate much time to studying the emission characteristics of this fuel. This research is concerned with a preliminary study of the emission characteristics of a compression ignition engine fuelled with methanol as the main fuel, and dimethyl ether (DME) as the ignition promotor. Tests were conducted at 1 550 rpm and 1 730 rpm with varying load. The results were then compared to those of baseline tests using diesel fuelling. The results showed that there was a considerable reduction in smoke emissions using methanol/DME fuelling. It was also found that there was a significant reduction in NO emissions. However, the CO_2 and CO emissions were found to be higher than the equivalent diesel baseline tests.

1 Introduction

Methanol was initially considered as an alternative fuel for its ability to relieve the world's dependence on crude oil. However, with increasingly stringent emissions legislation in Europe, United States and Japan its emission reducing qualities are now being investigated.

Methanol cannot solely substitute diesel in a compression ignition (CI) engine, because of its low cetane number (below 15). A pilot fuel or cetane improver is required. Much of the the research has been done on spark-assisted and cetane improved methanol combustion in a CI engine. Other methods include glow-plug assisted methanol combustion and dual fuelling of CI engine.[1,2,3,9]

Initial results of cetane improved methanol combustion indicate that the combustion is relatively free of particulate emissions (soot).[4] NO_x emissions showed a reduction of up to 50% compared to a conventional compression ignition engine. However, hydrocarbon and formaldehyde emissions were higher than diesel levels. CO emission levels were similar to those of diesel combustion.[5]

For this research dual fuelling was used to achieve methanol combustion in a CI engine. Dimethyl ether (DME) was aspirated into the cylinder where it initiated combustion, and then methanol was injected to sustain the combustion. The engine was capable of running solely on DME, but drastically reduced performance was ahieved.[6,7] The specific aims of the present work were to investigate the emissions resulting from the combustion of DME and methanol in a CI engine, keeping DME to a minimum while varying the load at constant speed. The exhaust emissions investigated were CO_2, CO, NO, NO_2, and the exhaust gas density (smoke).

2 Test facility and test procedure

The engine used for this work was a direct injection, two cylinder, water-cooled, four stroke Petter PH2W of compression ignition type. Load was applied by means of an eddy current dynamometer. The DME was aspirated into the air intake manifold, as close to the inlet valve as was possible.

One cylinder was fitted with a piezoelectric pressure transducer to measure combustion chamber pressure and a second piezoelectric pressure transducer was used to measure the fuel line pressure. The injector needle lift was recorded with a linear voltage differential transducer. These observations were used to monitor the engine performance.

A smoke meter was used to measure the exhaust gas density. Exhaust gases were analysed using an electrochemical sensing gas analyser coupled to a computer, to enable a real time graphical presentation of the results to ensure validity of the test. The gases measured were O_2, CO, CO_2, NO, and NO_2.

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Table 1 Emission results for diesel fuelling

Speed r.p.m.	Φ	T (Nm)	CO (ppm)	O_2 (ppm)	CO_2 (%)	NO_2 (ppm)	NO (ppm)	Smoke (HSU)
1 550	0.2	3	791	168010	3	6	332	2
	0.3	18	547	154223	4	20	675	14
	0.4	40	483	108485	7	107	1795	20
	0.5	53	1059	87789	8	101	2092	42
	0.7	60	4736	88272	9	82	1120	81
1 730	0.2	4	714	173771	3	7	308	16
	0.3	12	261	163216	4	11	528	27
	0.4	36	451	123390	6	64	1333	33
	0.5	51	1635	93048	8	98	1792	58
	0.7	59	6693	69321	10	68	1302	65

Table 2 Comparison of power output between diesel and methanol/DME

Equivalence ratio Φ	Diesel		Methanol and DME	
	1 550 r.p.m.	1 730 r.p.m.	1 550 r.p.m	1 730 r.p.m.
	Power (kW)		Power (kW)	
0.2	0.5	0.6	1.40	1.6
0.3	2.9	2.1	2.72	3.0
0.4	6.5	6.4	6.23	6.9
0.5	8.6	9.2	7.50	8.7
0.6	—	—	8.30	—
0.7	9.7	10.8	—	—

Table 3 Emission results for methanol/DME tests

Speed r.p.m.	Φ	T (Nm)	CO (ppm)	O_2 (ppm)	CO_2 (%)	NO_2 (ppm)	NO (ppm)	Ratio % D/M	Smoke (HSU)
1 550	0.2	8.7	3879	161399	3.5	22	142	57	3
	0.3	16.8	2795	147585	4.5	57	285	50	3
	0.4	38	1748	108365	7.5	100	1087	32	2
	0.5	46	2023	90263	9	52	1065	26	3
	0.6	51	1646	95260	8	58	1016	23	5
1 730	0.2	9.2	5171	156906	4	37	69	42	2
	0.3	16.8	3769	139578	16	38	180	51	2
	0.4	38	1585	79841	10	33	1129	40	4
	0.5	48	4539	47588	12	17	1471	34	9

3 Results

In order to facilitate the analysis of methanol/DME emission data, a complete set of diesel tests were conducted at similar speeds and loads. Two different speeds were chosen as a basis for the comparison, 1 550 rpm and 1 730 rpm.

3.1 Diesel Fuelling

Table 1 shows a summary of conditions and emission results for diesel fuelling.

At both 1 550 and 1 730 rpm, the emission for the diesel engine displayed the expected trends.

These are: at lower equivalence ratios ($\Phi = 0.2$) the CO emissions were initially high (± 700 ppm) then towards $\Phi = 0.4$ (± 450 ppm) emissions reached their minimum. As Φ increased to a value closer to stoichiometric ($\Phi = 1$) the CO emissions rapidly increased, in the region of $\pm 6\,000$ ppm.

The increase in CO at higher loads is attributed to the decreased amount of O_2 available to oxidise CO to CO_2.[8]

The NO emissions were negligible at low equivalence ratios ($\Phi = 0.2$) and increased to a maximum at $\Phi = 0.5$. The maximum value reached at this equivalence ratio was approximately 2 000 ppm. As the load continued to increase the NO emissions decreased to approximately 1 100 ppm. The initial increase in NO emissions with increase in load was attributed to the associated temperature increase in the cylinder. The formation of NO was directly linked to the temperature attained in the cylinder.[8] Figure 1 illustrates the trends for the diesel NO and CO emissions at both speeds.

The formation of NO_2 follows a similar trend to the formation of NO. However the quantities relative to the NO emissions are negligible, in the order of a maximum 100 ppm.

As the load increased the CO_2 emission increased. The smoke readings also increased with increase in load. As Φ is increased to a value above 0.7 the limit of 75 HSU was exceeded. Figure 2 illusrates the trends for both CO_2 and smoke at both speeds.

3.2 Methanol/DME fuelling

Few data are available in the literature on methanol/DME combustion. The results obtained could only be compared to diesel emissions. Table 2 shows a comparison of power for both fuelling conditions.

A comparison of the power rating between the diesel and methanol/DME clearly shows that at lower equivalence ratios ($\Phi = 0.2$) the power is greater for methanol/DME fuelling at both speeds.

The use of methanol/DME fuel allowed the engine to run at low equivalence ratios $\Phi = 0.15$ without any load compared to $\Phi = 0.2$ for the diesel fuel. However the upper load limit for the methanol/DME fuelling was lower than that for diesel fuelling, $\Phi = 0.6$ as compared to $\Phi = 0.7$ at speeds of 1 550 r.p.m. As the speed increased the methanol/DME upper limit was reduced to $\Phi = 0.5$ before the engine became unstable and misfired.

Table 3 shows a summary of the emission results for methanol/DME fuelling at both speeds. The ratio of DME to methanol decreases as the equivalence ratio and load are increased, as shown in Table 3. This is because the amount of DME aspirated into the manifold does not increase significantly with the increase in load. However the amount of methanol injected into the cylinder increases at a rapid rate with increasing load as it is necessary to release enough energy to sustain the load.

Figure 3 shows the smoke density versus equivalence ratio for both methanol and DME. The first major improvement of methanol/DME combustion over conventional diesel combustion was that the particulate emissions were drastically reduced. The values ranged from 2 to a maximum of 9 HSU over the entire load range, compared to values of 85 HSU at high loads for diesel combustion.

The curves relating CO emissions to the equivalence ratio for methanol/DME fuelling are shown in Figure 4. At both speeds the CO emissions were found to be very high at low loads, approximately 4 times greater than diesel values at the same load. As the load was increased the CO emissions decreased to a minimum of 2 000 ppm, which is double the amount of diesel CO emissions at the same load. Any subsequent increase in load caused a further increase in CO emissions.

Figure 5 indicates the curves relating NO emissions to equivalence ratio for methanol/DME fuelling. The NO emissions followed the same trend as the diesel equivalence emissions. They gradually increased with load to maximum then decreased with any further load increase. However the emission levels of NO at both speeds for methanol/DME combustion were much lower than diesel emission levels, in some cases more than 1 000 ppm lower.

The NO_2 emissions were also negligible compared to NO and CO values. The quantities of NO_2 in the exhaust were found to be of the same magnitude as the diesel NO_2 emissions.

The values of CO_2 increased with increase in load towards a maximum at stoichiometric combustion. The quantity of CO_2 in the exhaust was found to be larger than the quantity of CO_2 for diesel fuelling. The magnitudes of the CO_2 emissions are illustrated in Figure 6.

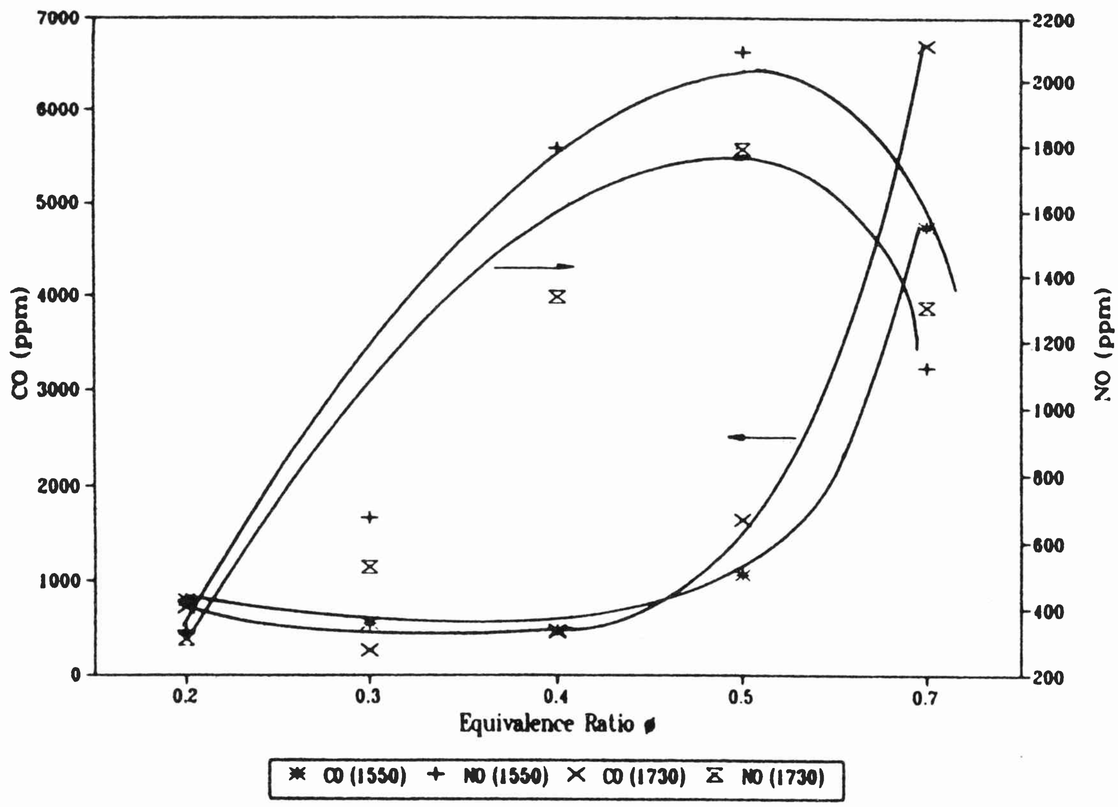

Figure 1 CO and NO emission for diesel fuelling *vs* equivalence ratio

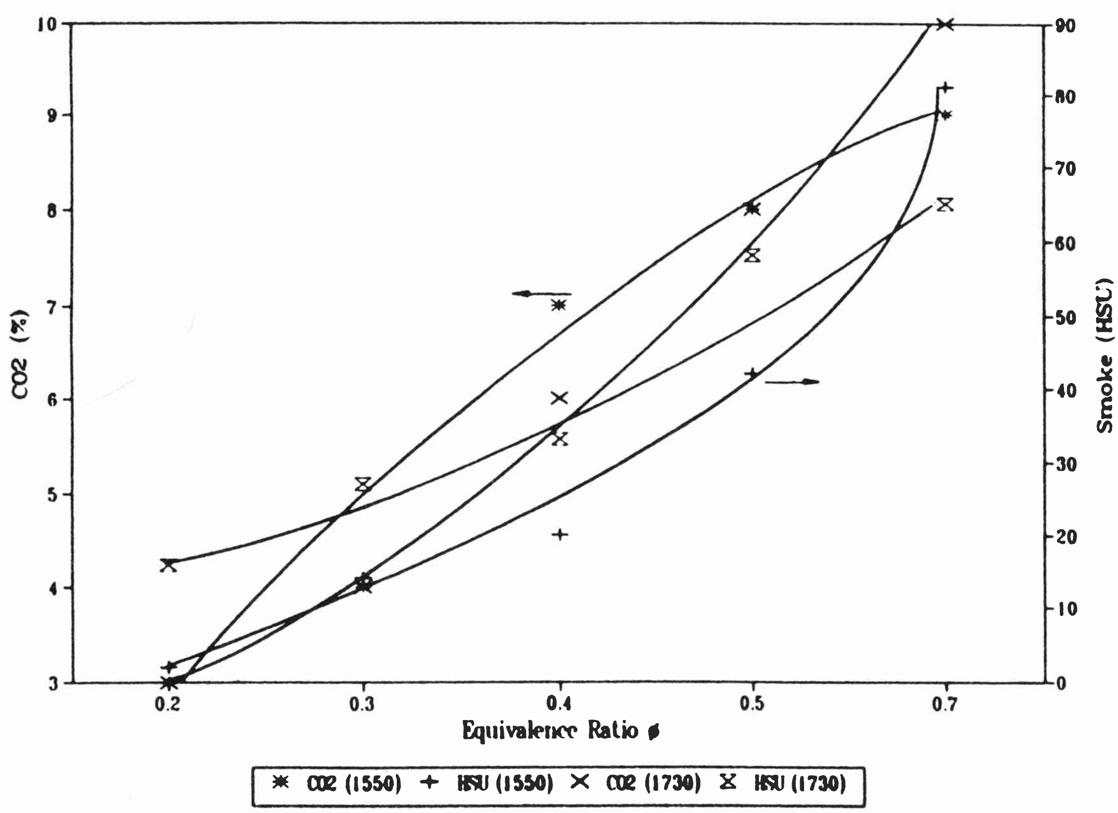

Figure 2 CO_2 and smoke emission for diesel fuelling *vs* equivalence ratio

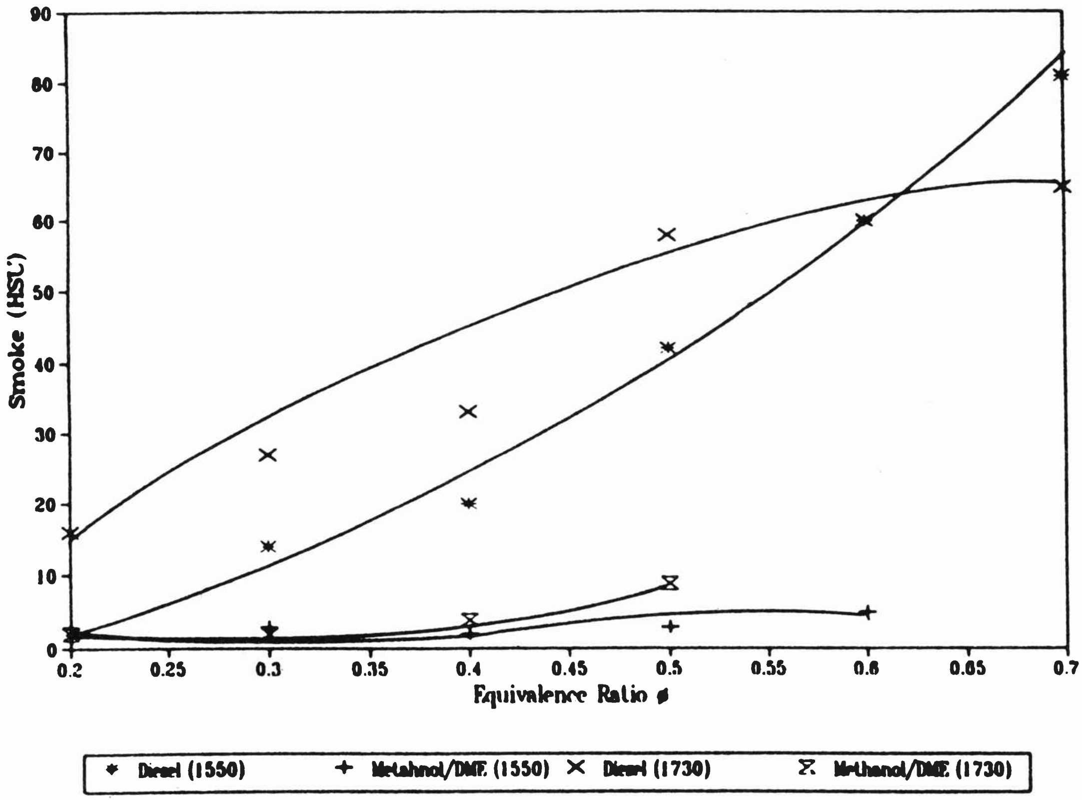

Figure 3 Smoke density for methanol/DME fuelling *vs* equivalence ratio

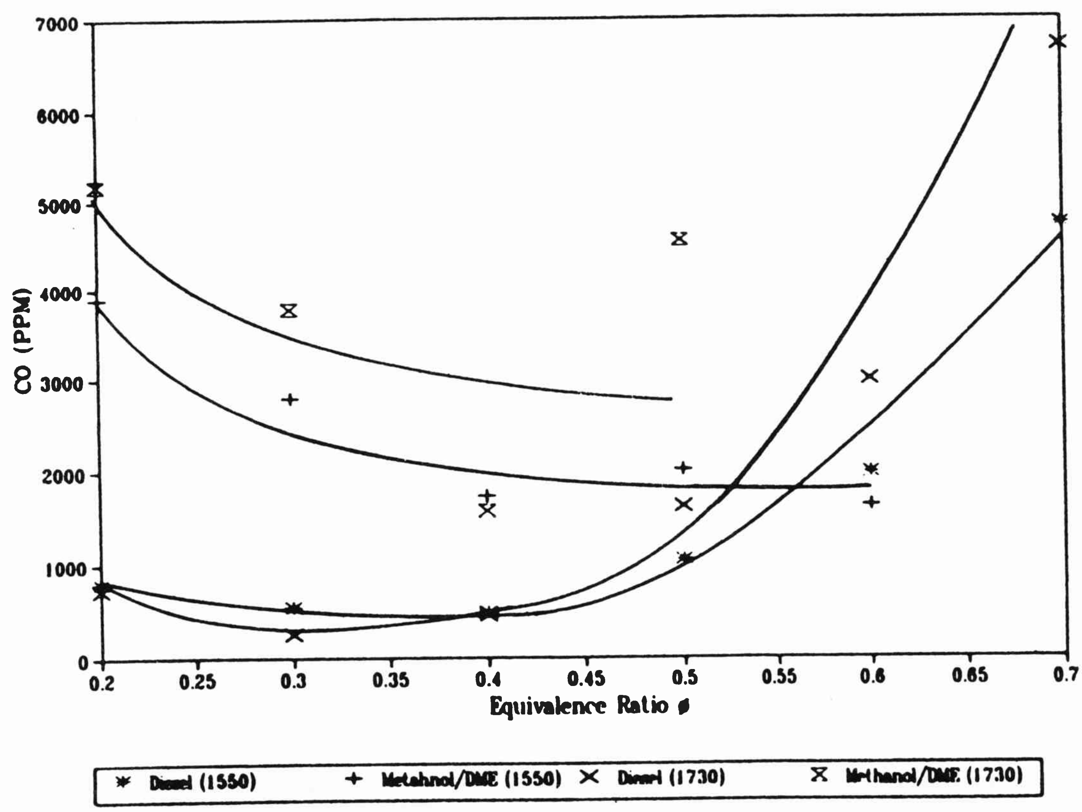

Figure 4 CO emissions for methanol/DME fuelling *vs* equivalence ratio

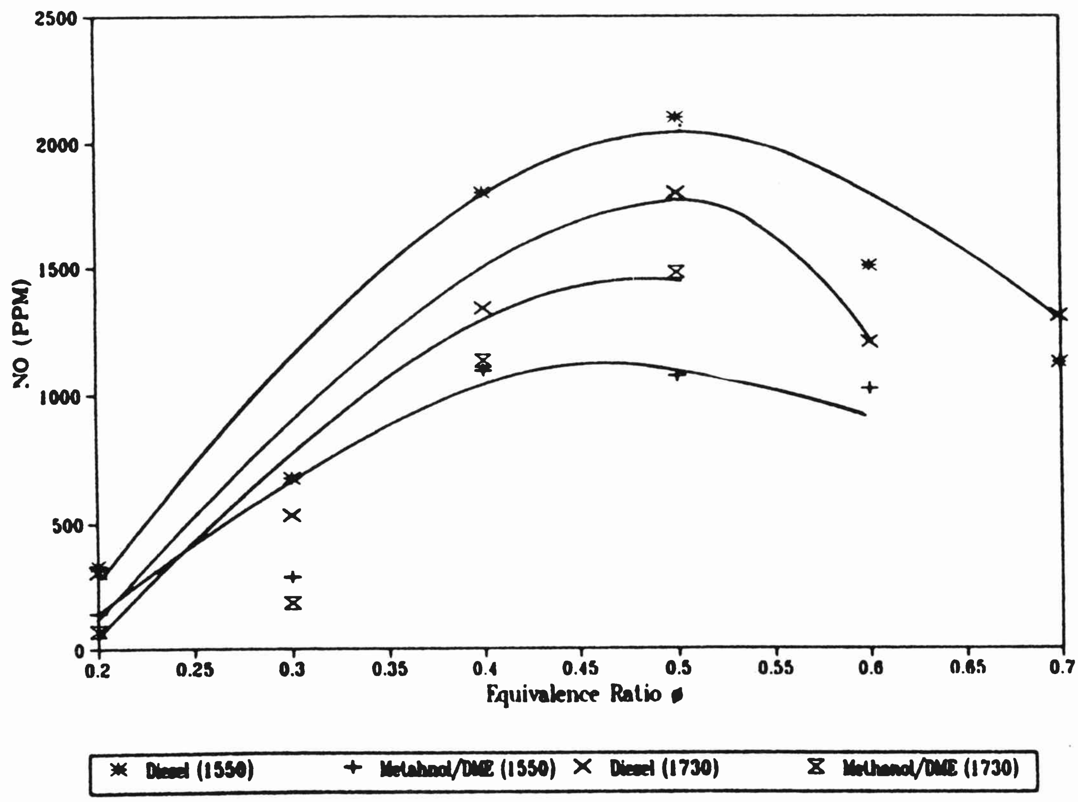

Figure 5 NO emissions for methanol/DME fuelling *vs* equivalence ratio

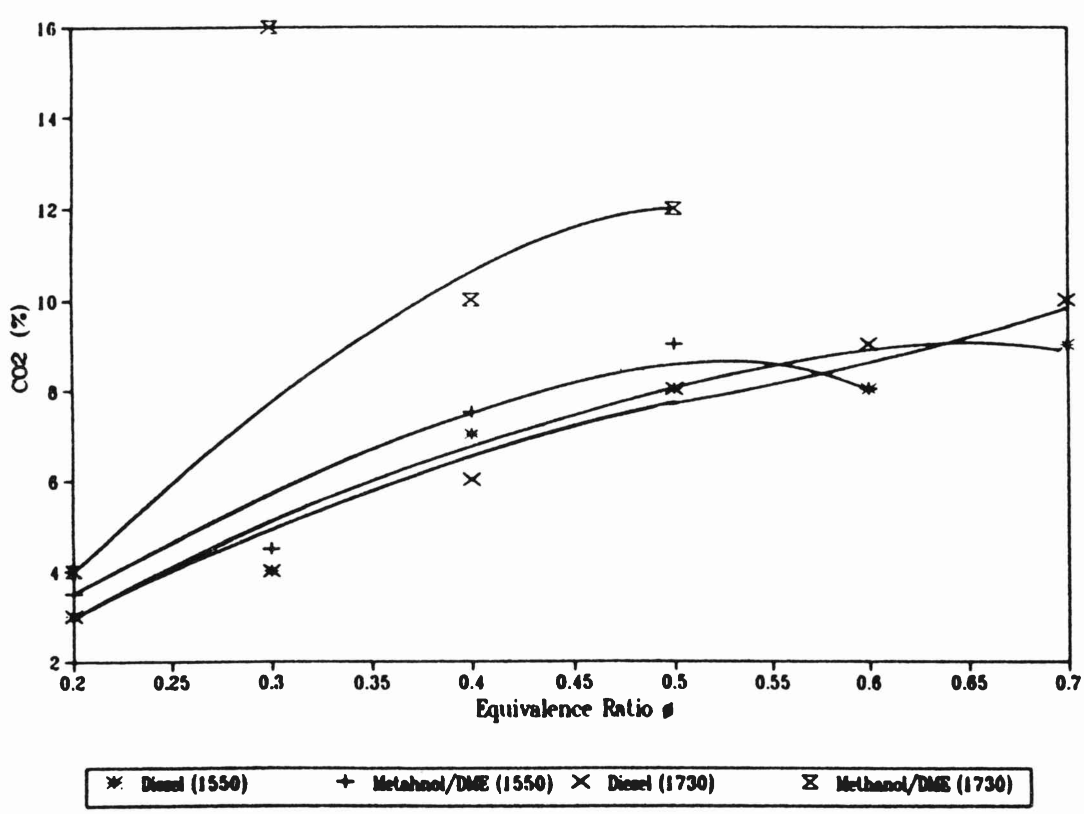

Figure 6 CO_2 emissions for methanol/DME fuelling *vs* equivalence ratio

4 Conclusion

The emissions formed from the combustion of methanol/DME in a CI engine are an improvement on the emissions formed during combustion of the diesel fuel. This can be noted in the following aspects:

- A definite reduction in particulate and smoke emissions is achieved using the methanol/DME dual fuel combination.
- A significant reduction in the NO emissions at higher loads is also achieved;
- the CO_2 and CO are significantly higher than diesel combustion emissions.

5 References

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