Diesel Engine Operation with Vegetable Oil - Alcohol Emulsion

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ABSTRACT

Results of single-cylinder, direct-injection diesel engine tests for a range of loads at two speeds for emulsions with 10 per cent (by volume) of ethyl alcohol of a commercial seed-based oil are presented. Values of ignition delay, specific fuel consumption, thermal efficiency and equivalence ratio and exhaust gas concentrations of carbon monoxide, carbon dioxide, oxides of nitrogen and smoke particulates are given.

Comparison is made between the magnitudes of the measured parameters for the emulsion of vegetable oil with alcohol and those for diesel fuel, vegetable oil and an emulsion of this with water.

The effect of emulsification with alcohol was, in general, to increase carbon monoxide and reduce oxides of nitrogen emissions. Effects on ignition delay and smoke were different at different engine speeds.

INTRODUCTION

The diesel engine has been found to be versatile in the range of fuels on which it can be operated, including non-petroleum based oils. Performance superior to that to be expected from low cetane number fuels has been achieved under conditions found in normal diesel engine operation (Henein, 1987).

Exhaust gas pollutant species levels for diesel engines are lower than those for spark-ignition engines not equipped with exhaust-gas catalytic converters (Helmer, 1991 and Lies, 1989). A major problem to be encountered with the more widespread use of the diesel engine, however, is that of the emission of particulate matter (smoke) in the exhaust gas under certain conditions.

Interest in the use of plant-oil derived fuels for the diesel engine has currently been revived, these oils being similar in structure and composition to diesel fuels (Henhem and Johns, 1990). Vegetable-derived oil is considered to be a viable immediate alternative source of energy, particularly for on-farm use (in diesel-powered machinery) in non-oil producing, agriculture-based developing economies. Here the cost of loss of crops due to a sudden fuel shortage would be expected to outweigh the extra cost of vegetable oil over that of diesel fuel. The use of these fuels is not however trouble free and a number of problems such as cold-start, lubricating oil degradation and fouling of the injector nozzles used to admit the atomised fuel spray into the combustion chamber, have been encountered. They have the advantages of being widely available (Lowry, 1990) in a variety of products and of being renewable (and so not exerting as large an effect as fossil fuels on global carbon dioxide levels).

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A possible means of overcoming the problems, and reducing the emissions of oxides of nitrogen is to emulsify the fuel with a small proportion of water (Crookes *et al.*, 1980) .This leads to improved atomisation (possibly through the phenomenon of *micro-explosion*) and to lower combustion chamber temperatures. Ethyl alcohol presents a novel combustible alternative to water having a lower boiling point and a high enthalpy of evaporation. It has been considered as a possible fuel for the diesel engine (Henhem and Johns, 1990) but requiring spark-assisted ignition.

The present work compares the effects of emulsification with water and ethyl alcohol on the ignition and subsequent combustion properties of an unmodified proprietary vegetable oil with the properties of a conventional diesel fuel. Simplicity and ease of application of the possible solution to the problems associated with the use of vegetable oil as a fuel for diesel engines, governed the selection of the method of investigation used in the present work. Ethanol was selected as a readily produced additional bio-product. Emulsification was carried out by a simple in-line mechanical device without additional emulsifying agents, which could have had an effect on the combustion process.

EXPERIMENTAL

The experimental installation used in the work presented here consists of a single-cylinder direct-injection Gardner (1L2) research diesel engine (see *Table 1* for engine specification) with associated performance and emissions

TABLE 1. GARDNER ENGINE SPECIFICATION

Model	IL2
N° cylinders	1
bore/mm	107.95
stroke/mm	152.4
Total Capacity/10^{-3} m^3	1.51
Clearance volume/10^{-6} m^3	115.15
Compression ratio	14 : 1
Max power/kW @ r/min	14.4 @ 1500
Inlet valve opening/°btdc	10
Inlet valve closing/°abdc	40
Exhaust valve opening/°bbdc	50
Exhaust valve closing/°atdc	15
Injection timing/°btdc	24.5
Injector nozzles	4
Nozzle throat dia/10^{-6} m	220
Injector opening pressure/MPa	16.2

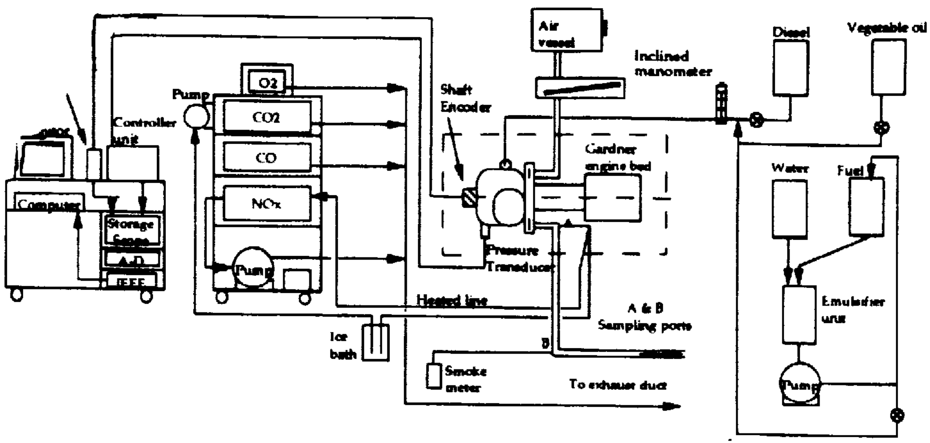

Figure 1. schematic diagram of experimental installation

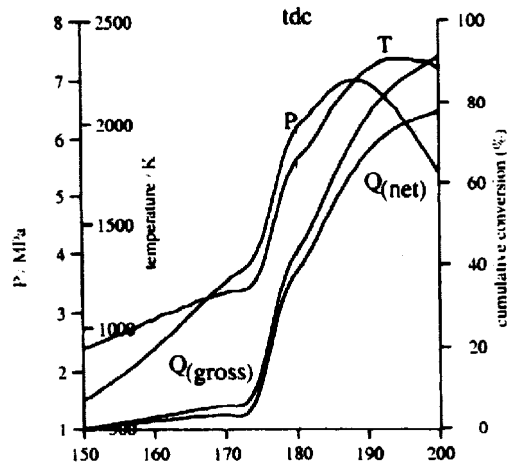

Figure 2. Variation with crank angle of pressure, temperature and cumulative reaction with (gross) and without (net) heat transfer for vegetable oil : 10% ethyl alcohol (by volume) emulsion at 1500 r/min and 0.6 bmep.

instrumentation (*Figure 1*) (Crookes *et al.*, 1990). A range of load settings up to maximum power was used at two constant speeds (750 and 1500 r/min) with fixed injection timing (24.5 °btdc (degrees before top-dead-centre)) and constant compression ratio (14:1) for each of the fuels examined.

Dry (neat) diesel fuel (Derv) and vegetable oil (equal volumes of rapeseed and soya oils) base fuel and emulsions of this with 10 per cent by volume of water, and 10 per cent by volume of ethyl alcohol were tested. The emulsions were prepared continuously (dynamically), immediately prior to injection by means of a high-speed rotary (*Dynatrol*) mixing device producing a high shearing rate and cavitation in the fuel-water or alcohol mixture.

Multiple cylinder pressure - crank angle signals from a *Kistler* (6123) pressure transducer and a *Digitech* (1052) shaft encoder were digitised and stored using a *Gould* (OS 4200) digital storage oscilloscope interfacing through an IEEE A-D converter with a micro-computer. A purpose-built signal conditioner provided triggering signals and a top-dead-centre marker for the oscilloscope. A sampling rate of 720/revolution (one half-degree crank angle) was used. The signals were each mathematically averaged, smoothed and individually processed using in-house software to generate *ignition delay* and reaction rate (*heat-release rate*) data using a PC based system. Samples of non-consecutive cycle raw and processed data-sets were compared for repeatability. Fuel-line pressure was monitored by means of a *Kistler* (4064) transducer.

Exhaust gas species, sampled near the exhaust valve, were measured by means of a *Luminox* chemiluminescence, oxides of nitrogen analyser (via a tape-heated line), *ADC* non-dispersive infra-red carbon monoxide and dioxide analysers and a *Servomex* paramagnetic oxygen analyser. A *Bosch* smoke meter was used to determine smoke levels in samples drawn through filter papers in the associated probe unit fitted directly to the engine exhaust pipe.

RESULTS AND DISCUSSION

Ignition and Combustion

Rates of reaction values were computed from the pressure-crank angle data assuming conservation of energy, ideal gas properties and heat transfer to the cooling water (Crookes, *et al.* 1990). Ignition delay values were taken from the reaction-rate record. Ignition was judged as occurring at the instant that the reaction rate changed from negative to positive. The manufacturer's setting was taken as the start of injection.

Figure 2 illustrates the profile of the pressure-crank angle record in the compression and expansion strokes at maximum attainable load (brake mean effective pressure (bmep)) condition (0.6 MPa) at 1500 r/min for vegetable oil: 10 per cent (by volume) ethyl alcohol emulsion. Corresponding temperature and cumulative fuel energy conversion profiles, computed from the pressure data, are also included. [Energy conversion profiles are presented, in which heat transfer to the engine cooling water has both been accounted for (gross) or neglected (net)]. Good repeatability of non-consecutive cycle records has been demonstrated (Crookes *et al.*, 1992) (typical variations in ignition delay and peak combustion pressure are of the order of 1%).

In *Figure 3*, pressure and rate of reaction profiles are presented at both speeds for the two base fuels with the 10 per cent water and ethyl alcohol emulsions at equal loads. The fuel-line pressure is also given for the alcohol emulsion. At the higher speed and load condition (1500 r/min at 0.5 MPa) there is little difference between the profiles for both base fuels and for the two emulsions. At the lower speed and load condition, (750 r/min at 0.4 MPa) all the vegetable oil curves lag behind the diesel fuel. The alcohol emulsion exhibits the shortest delay of the vegetable oil fuels.

The values for all fuels generally decrease, and converge with increased speed and load. Ignition-delay for a liquid fuel spray is influenced by the fuel type and the temperature of the surrounding gas. The cetane number classification is, however, less descriptive of the initiation behaviour at the operating conditions of temperature and pressure prevailing in modern diesel engine practice (Crookes *et al.*, 1992). The emulsions have generally higher premixed peaks than the dry fuels.

Trends in ignition delay values are illustrated in *Figure 4*, along with the variation of other parameters with load, for all the fuels tested and both speeds. Specific fuel consumption falls for all fuels with load. Values for emulsions and dry fuels are close. The values for vegetable oil fuels, having lower specific combustion enthalpies, are higher. Thermal efficiencies are comparable with the diesel fuels performing somewhat better at lower speed and load conditions and the vegetable oil fuels better at higher speed and load. However, the highest efficiency appears to result from the alcohol vegetable oil emulsion tests. Equivalence ratio increases with load in all tests.

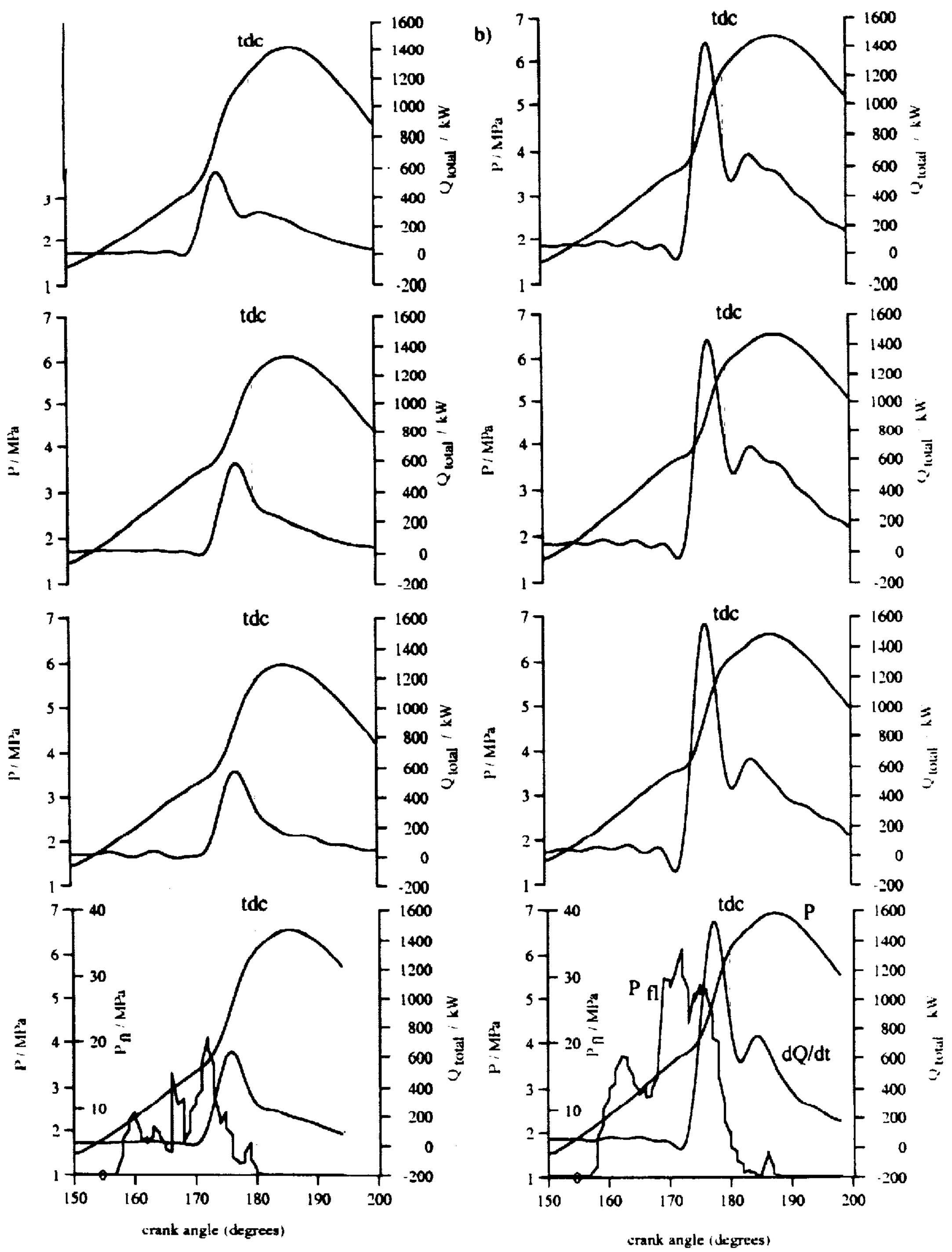

Figure 3. Variation with crank angle of pressure, rate of reaction (gross) and fuel line pressure for diesel fuel, vegetable oil and vegetable oil emulsions with 10% water and 10% ethyl alcohol (by volume) a) at 750 r/min and 0.4 MPa bmep and (b) at 1500 r/min and 0.5 MPa bmep

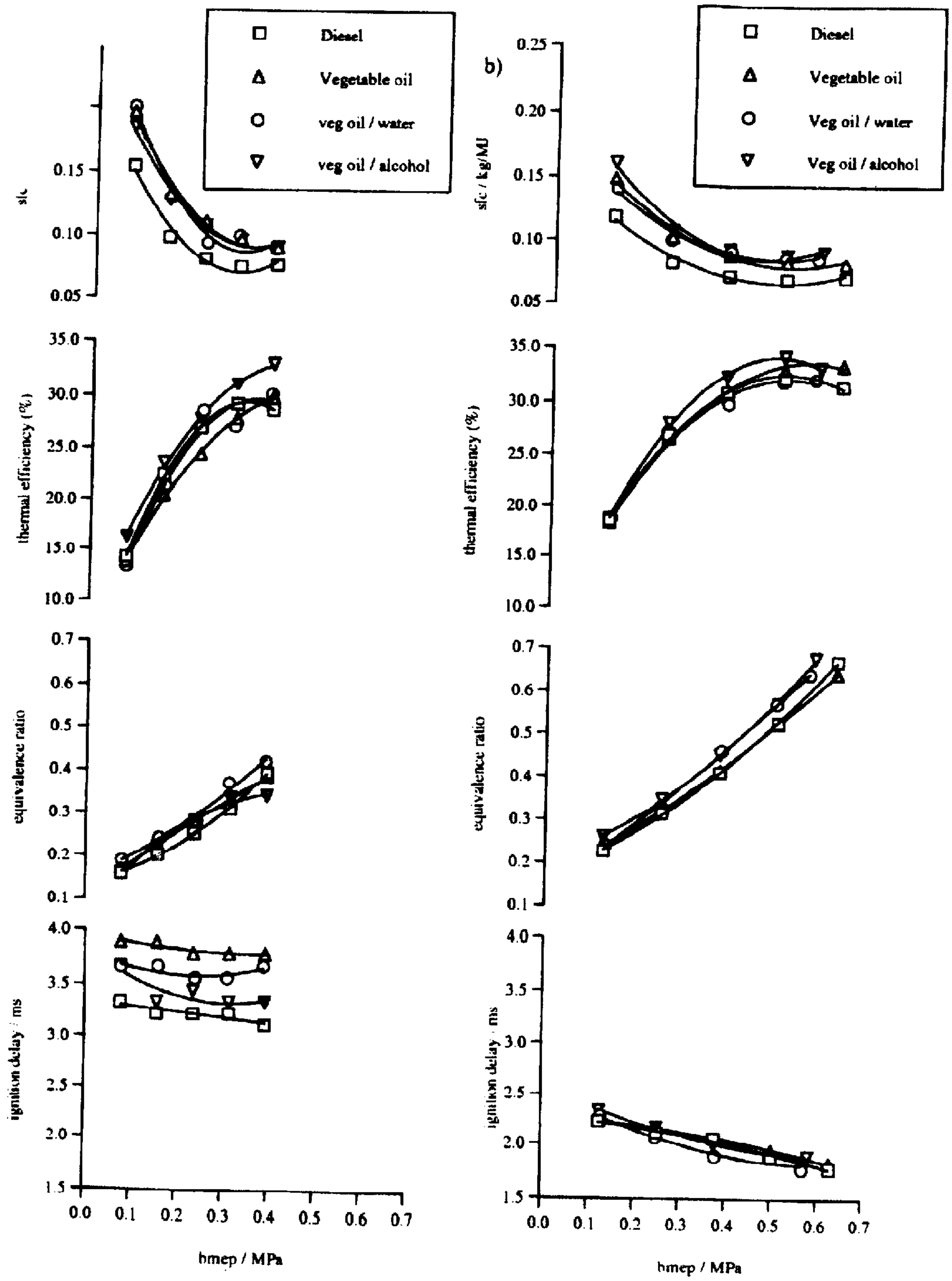

***Figure 4.** Variation with bmep of ignition and combustion parameters for diesel fuel, vegetable oil and vegetable oil emulsions with 10% water and 10% ethy alcohol (by volume) a)at 750 r/min and b) at 1500 r/ min*

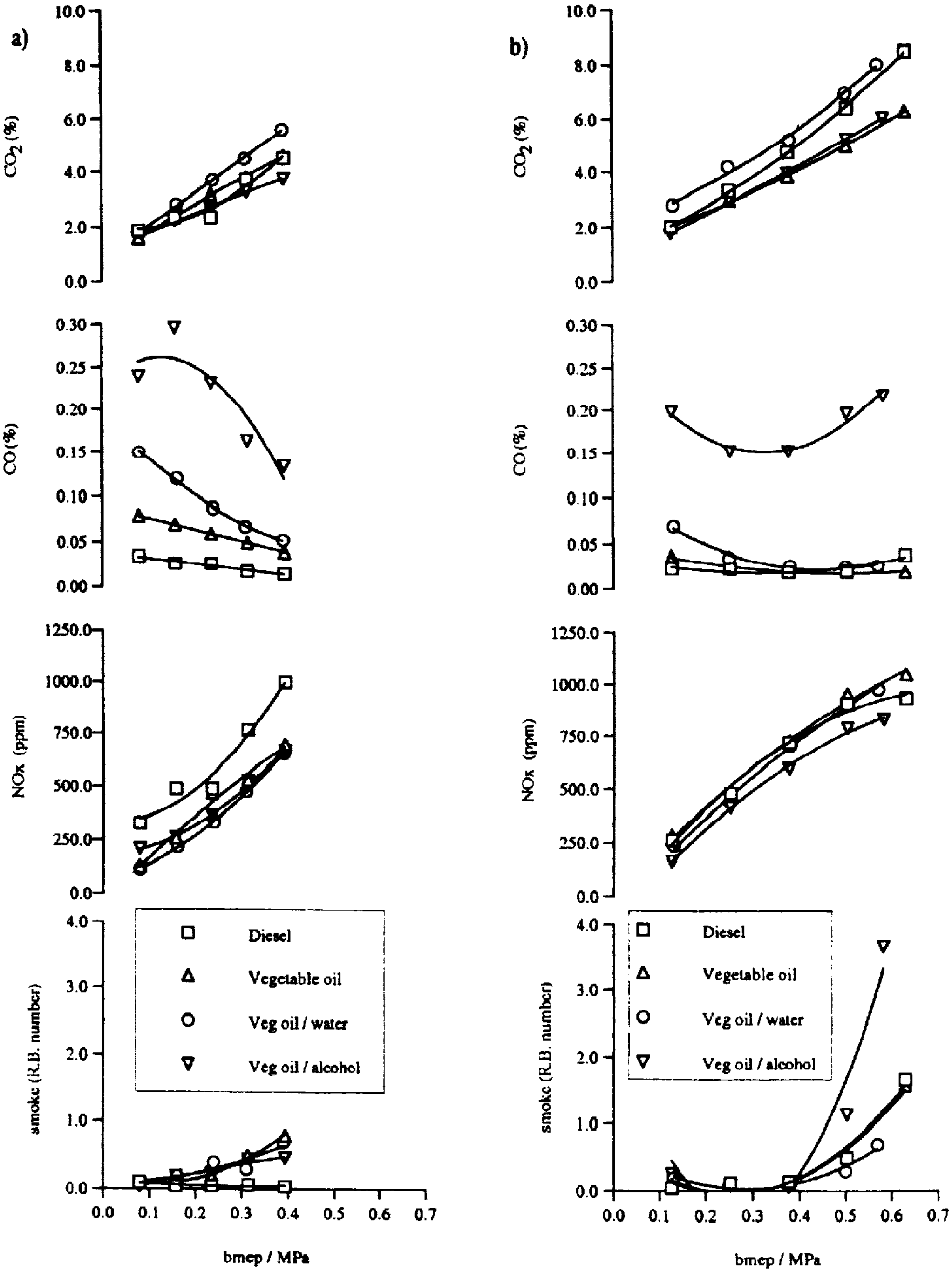

Figure 5. Variation with bmep of exhaust emissions for diesel fuel, vegetable oil and vegetable oil emulsions with 10% water and 10% ethyl alcohol (by volume) a) at 750 r/min and b) at 1500 r/min

Exhaust gas emissions

Figure 5 shows the variation in measured emissions for the same operating conditions as in *Figure 4*, in relation to load. Carbon monoxide values are low and reduce with increased load (and equivalence ratio). They are lower for the base fuels and highest for the alcohol emulsion. Carbon dioxide and oxides of nitrogen concentrations and the Bosch smoke number all increase with load. Vegetable oil and its emulsion with alcohol produce marginally lower CO_2 levels. Since the vegetable oil based fuels are renewable moreover, they do not involve to the same extent (taking account of production process releases), the liberation of fixed carbon from fossil fuel deposits (Culshaw, 1993). Oxides of nitrogen are lower for the vegetable oil fuels at the lower speed but lowest for the alcohol emulsions at the higher speed. Smoke levels are lower for the diesel fuel. At the higher speed, the vegetable oil alcohol emulsion has the highest smoke numbers. Observation of the opposite variations of emissions of NO_x and particulates with changes of operating variables have been expressed as a so-called "trade-off" in these species. The values obtained with emulsification with ethyl alcohol are consistent with this. Earlier work had shown emulsification with water to reduce both species and break the trade-off (Crookes *et al.*, 1990 and 1992).

In these tests it has generally been the case that the NO_x concentrations increase as the ignition delay decreases (*Figures 4 & 5*) for a given speed and fixed injection timing. This relation is consistent with the counter effects of preheating the engine intake air and emulsification of the fuel with water on these parameters, observed in the work of Afifi *et. al.*, 1987, with diesel fuel. The effects were explained in terms of temperature with the main influence attributed to the evaporation of water with the emulsified fuels.

Effect of emulsification with ethyl alcohol

In general, there appear to be improvements in operation with vegetable oil to be made by emulsification with 10% by volume of ethyl alcohol. These are not, however, the same as the improvements with water emulsification (Crookes *et al.*, 1990 and 1992 and Afifi *et al.*, 1987). The ignition and thermal efficiency are enhanced and oxides of nitrogen reduced in operation with the alcohol emulsion. Emissions of carbon monoxide and smoke, however, are increased.

On balance, it would appear that though operation with alcohol emulsion is better than with vegetable oil alone, the advantages are no higher than for emulsification with water.

CONCLUSIONS

1. Vegetable oil, vegetable oil:water and vegetable oil:ethyl alcohol emulsions have been found to exhibit similar performance and broadly similar emissions levels to standard diesel fuel under equivalent engine operation conditions.
2. Whereas emulsification with water appears to be effective in reducing the emissions of both oxides of nitrogen and smoke, emulsification with ethyl alcohol reduces oxides of nitrogen and increases smoke and carbon monoxide levels.
3. Ignition delay decreases with increasing load and the values for vegetable oil are close to those for diesel fuel at the most extreme conditions tested. Under these conditions the emulsified vegetable oil alcohol fuel exhibits approximately the same delay.

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