EMISSION CHARACTERISTICS OF COMPRESSION IGNITION ENGINE FUELLED WITH RME/DF AND ETHANOL

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Abstract

Comparison of emissions from CI engine fuelled with diesel fuel (DF) and rape oil methyl ester (RME) in function of load was carried out. The results in general are similar for both fuels. In order to reduce emission, a novel concept of fuelling was developed. According to this concept, ethanol is injected to the inlet port during the inlet stroke to support burning of the main fuel. Experiment was carried out with the use of one-cylinder direct injection diesel engine adapted for ethanol injection. Investigations were performed at two constant loads, for which the ratios of ethanol and base fuel were changed: high and low, at each load engine was run at three speeds for three injection timings. Results of investigation showed considerable decrease of CO_2 emission and smoke level for all operating conditions of the engine load – at high load – also CO and HC emissions, while at low load – NO_x emission. Optimum ratio of ethanol energy to both fuels energy on account of emission decrease was found to be about 20 for DF and 25 percent for RME.

1. Introduction

For the last two decades a worldwide trend of biofuels application to internal combustion engines has been observed. These fuels are mainly vegetable oils and alcohols. However, vegetable oils have very high viscosity in comparison with that of diesel fuel (DF) and therefore they did not commonly enter the fuel market. They are base materials for fabrication of fatty acid methyl esters (FAME), which have much lower viscosity in comparison with crude vegetable oils, comparable to this of DF and/or are added to diesel fuel as fractions. Rapeseed oil methyl ester (RME) and alcohols are these renewable biofuels which have been used for some time in Western Europe, South Asia and South and North America. Presently they will be used in Poland as components to diesel fuel and gasoline, respectively.

As far as ethanol application to CI engines is concerned European Commission expects that bioethanol will be introduced into European markets as blends with diesel fuel E15D (15% of ethanol in diesel fuel) [2]. Until now Scania S.A. launched a couple of city-busses which are fuelled with the blend of 5% (by vol.) of ethanol and 95% of diesel fuel [2].

A lot of work has been done in Europe (France, Austria, Germany, Poland) and America since early nineties on application of RME to CI engines, e.g. [4-7].

The results of experiments carried out on fuelling with neat RME and/or its blends with DF are as follows:

- RME as individual fuel (neat) may be applied to CI engines but inspection of fuelling system, especially injectors, should be carried out more often [5],
- brake fuel conversion efficiency of the engine fuelled with RME is a little better than for fuelling with DF, mainly for middle speed,
- ignition delay of RME fuel and its blends with DF is shorter than for neat DF,

- all emissions (except for NO_x) of the engine fuelled with RME are lower than for fuelling with DF,
- wear of the engine is higher for fuelling with RME than for DF but, after exchange of some plastic and rubber elements, is comparable to that for DF,
- as far as mixtures of RME and DF are concerned, 30% fraction of RME demands no exchange of engine elements, does not influence engine performance and emissions, even improves them.

In this paper once again the comparison of emission of CI DI engine fuelled with neat RME and neat diesel fuel (DF) is carried out. This comparison did not give an expected advantage of fuelling the engine with RME (except for the obvious benefit with CO_2 net production equal to null), so a new concept of more ecological engine was developed. This novel engine was fuelled with DF or RME as a base fuel and additionally with ethanol in order to promote combustion of DF or RME.

2. Engine test stand and course of investigation

Engine data are given in Table 1. Test stand is shown in Fig. 1.

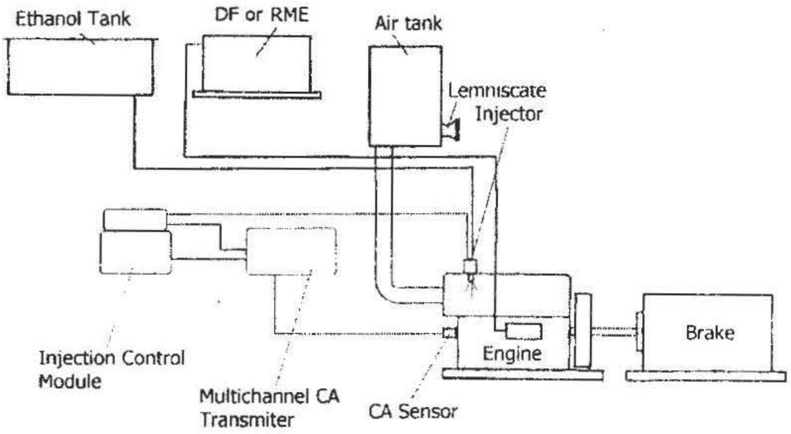

Fig. 1. Test stand

Table 1. Engine data

Type of the engine	1HC102 (Polish production)
No. of cylinders	1
Swept volume	980 cm^3
Compression ratio	17
Bore/Stroke	102/120 mm
Max power	11 kW at 2200 rpm
Max torque	55 Nm at 1500 rpm
Injection pump*	plunger type
Injector nozzle	pintile type
Orifice diameter	0,95 mm
Injection pressure	13,2–14,2 MPa

Standard fuel injection pump was replaced by another one, giving higher fuel delivery

Engine torque was measured by means of the eddy-current dynamometer Vibrometer 3WB15. RME fuel consumption was measured with the use of the automatic dosemeter PG-80. Ethanol dose per cycle was measured indirectly by measuring the time of consumption of its definite mass. Air flow was measured with the use of a flowmeter installed on the inlet air surge tank which reduced pressure pulsation. Exhaust gas analysis, especially measurement of CO, CO_2, HC, air excess ratio λ and smoke level, was carried out with the AVL 465 DiGas analyser. NO_x emission was measured by the Beckman analyser Model 951. Also HC was measured with the Beckman analyser Model 402.

Properties of fuels used in experiments are given in Table 2.

Table 2. Physico-chemical properties of diesel fuel, RME and ethanol

Property	DF	RME	Ethanol
Chemical formula	-	-	C_2H_5OH
Molecular weight, g/mol	~170	-	46
Density @ 20°C, kg/m^3	838	878	789
Calorific value, MJ/kg	41,03	38,5	2,69
Calorific value of stoichiometric mixture, MJ/kg	-	-	3,85
Heat of evaporation, kJ/kg	270	250	840
Temperature of selfignition, K	~500	~400	665
Stoichiometric air/fuel ratio, kg air/kg fuel	14,5	13,6	9,0
Lower flammability λ_l	0,98	-	2,06
Higher flammability λ_h	0,19	-	0,30
Kinematic viscosity @ 40°C, mm^2/s	2,97	4,58	1,4
Octane number motor (MON)/research (RON)	-	-	89/107
Cetane number	58	60	8
Flame temperature, K	-	-	2235
Molecular composition (by mass)			
C	0,870	0,775	0,522
H	0,130	0,121	0,130
O	-	0,104	0,348

3. Comparison of emissions of the engine fuelled with neat RME and diesel fuel

At first comparison of emissions of the engine fuelled with neat diesel fuel and rape oil methyl ester was carried out. In order to determine optimum injection timing of the fuel, emissions were measured for injection timing 25 and 35 deg of CA BTDC in the full range of load at 1200 rpm. As a result of this experiments, the angle of beginning of injection was selected to be 25 deg BTDC for both fuels.

Comparison of emissions for fuelling with DF and RME were performed in function of engine load for three speeds: 1200, 1800 and 2200 rpm and injection timing 25 deg BTDC. Results of this experiment are shown in Figs 2-7.

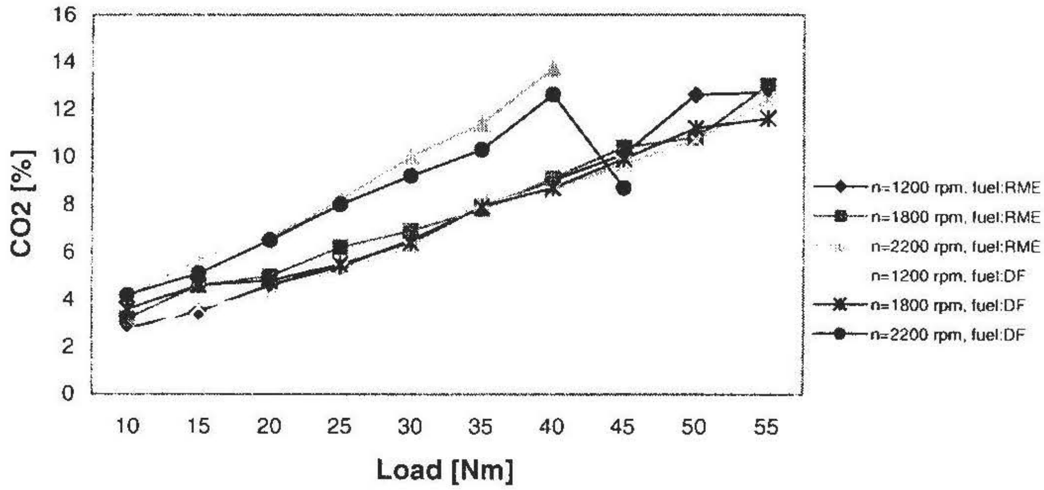

Fig. 2. Comparison of greenhouse gas emission vs. load for fuelling with RME and DF

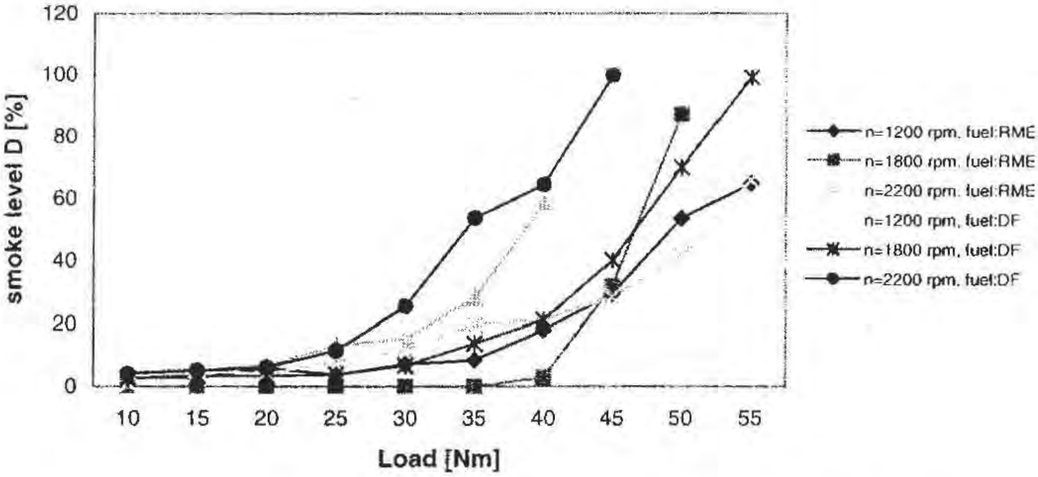

Fig. 3. Comparison of smoke emission vs. load for fuelling with RME and DF

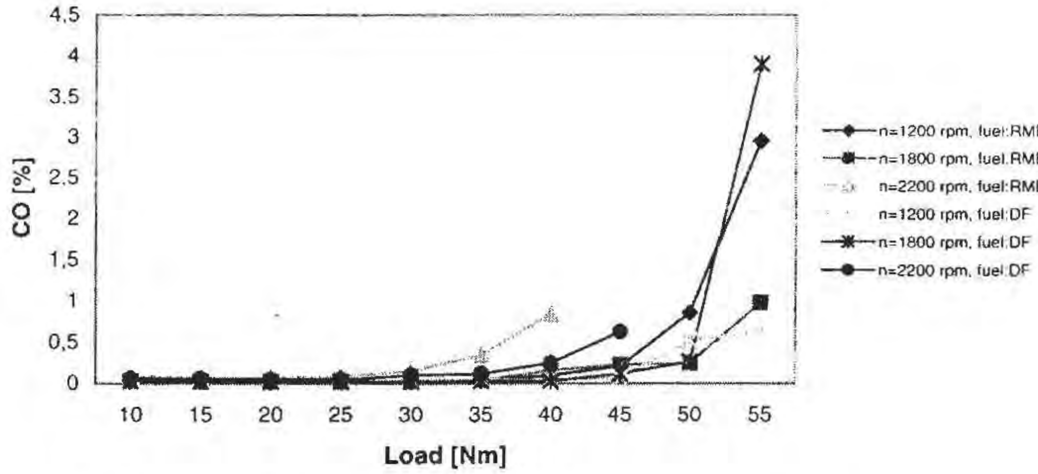

Fig. 4. Comparison of carbon oxide emission vs. load for fuelling with RME and DF

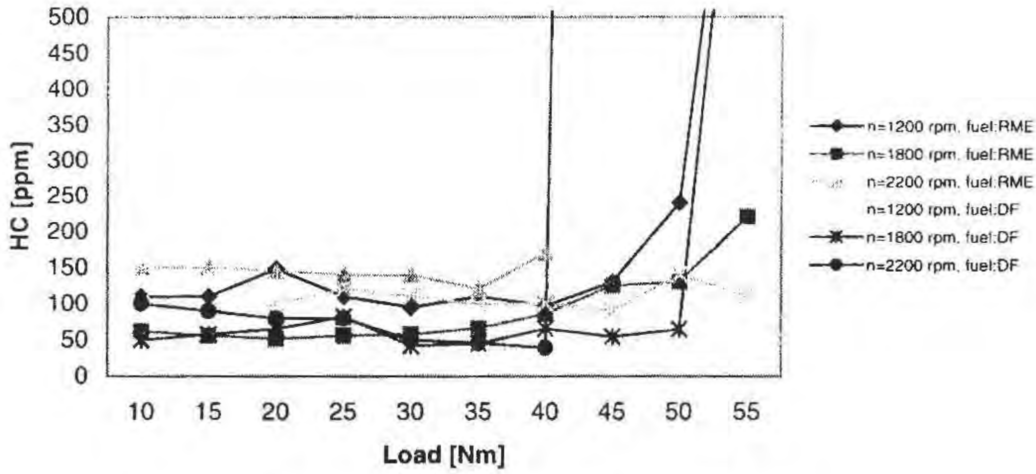

Fig. 5. Comparison of hydrocarbons emission vs. load for fuelling with RME and DF

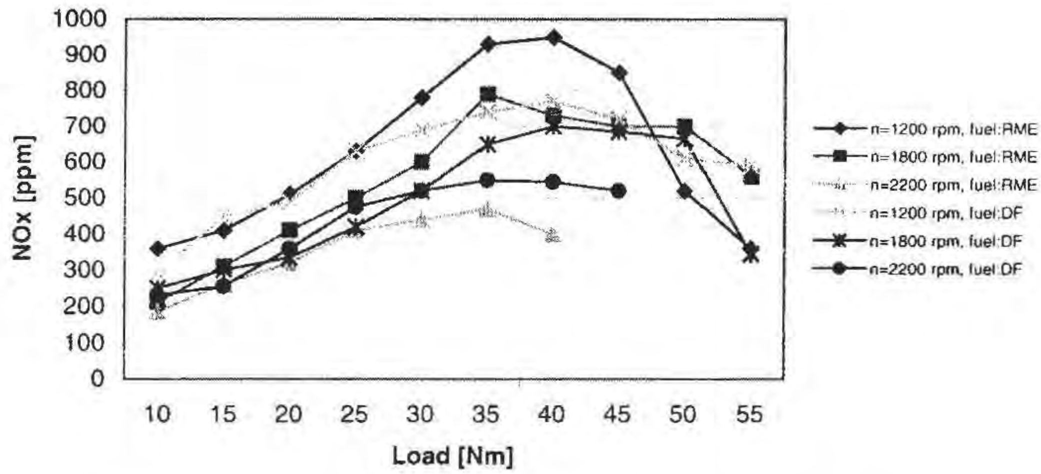

Fig. 6. Comparison of nitric oxide emission vs. load for fuelling with RME and DF

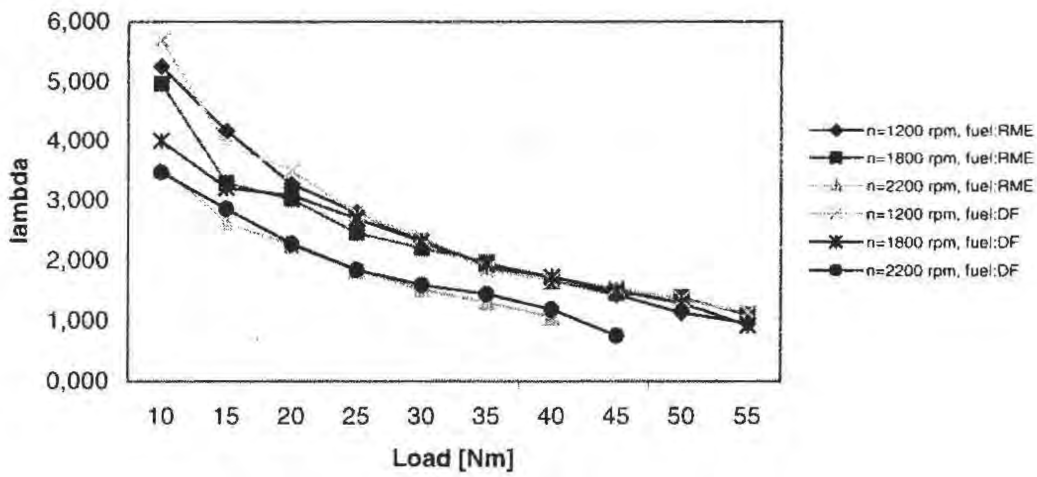

Fig. 7. Air excess coefficient vs. load for fuelling with RME and DF

As may be seen, excluding the cases $\lambda \leq 1$ (high load and speed) CO_2 and smoke emissions (excluding high speed) are almost the same, while CO and HC emissions are higher for RME fuel. NO_x emission is higher for RME at low and middle engine speed, while at high engine speed and load – lower for RME. The following reasons of these results may be given. CO_2 and smoke emissions are comparable, because fuel energy consumption is similar. As far as CO and HC are concerned, higher emission results from the fact that not all fuel is burnt due to longer combustion of RME than DF. NO_x emission is lower for RME at high speed and load, when less fuel is burnt in comparison with DF. Normally, temperature of combustion of DF is higher than this of RME.

4. A novel concept of an ecological engine

Application of RME instead of diesel fuel doesnot improve emission characteristics of the engine in the degree as expected. Therefore a novel concept of diesel engine was invented, developed and investigated in Technical University of Radom. The concept consists in dual fuelling: a base fuel, which – in the first approach – is diesel fuel (DF) and – in the second approach – rape oil methyl ester (RME) is injected by the standard fuel system and additionally, ethanol is injected into the inlet port during the suction stroke, in order to enhance burning of DF/RME fuel droplets. Before self-ignition of DF/RME ethanol forms with air homogeneous mixture. After ignition by burning DF or RME droplets (which have self-ignited earlier), ethanol vapour – air premixed combustion accelerates burning of DF/RME droplets, and – as a result – combustion period is shorter. In such a way the total time from the beginning of DF/RME injection to the end of combustion may be shortened, resulting in smokeless combustion. At this moment it is worthy to mention, that while fuelling an engine with RME, which is a biofuel, net production of the greenhouse gas (carbon dioxide, CO_2) is equal to zero. Moreover, due to the fact that ethanol has higher mass ratio of hydrogen to carbon (H/C ratio) in the molecule than DF, lower emission of greenhouse gas is expected.

The results of investigation on dual fuelling with diesel fuel and ethanol was presented in the former work of the author and co-author [3]. Presently, the main fuel – diesel fuel – is replaced by rape oil methyl ester (RME) and engine emissions are compared for these two base fuels.

5. Influence of ethanol addition on emission characteristics of engine fuelled with DF and RME

5. 1. Course of the experiment

In this experiment the comparison of emission characteristics of the engine fuelled with diesel fuel and rape oil methyl ester in function of the ratio of ethanol energy to both fuels energy (i.e. DF or RME) Ω_E was carried out.

Investigation was carried out at two loads: 20 Nm and 40 Nm; at each load the three speeds: 1200, 1800 and 2200 rpm and three injection timing of base fuel: 25, 30 and 35 deg BTDC. Measurement points were chosen in such a way, that the comparison of engine parameters and emission could be obtained for the same load but for different proportions of ethanol to base fuel (DF or RME).

Emissions were measured in the function of the ratio of ethanol energy to the energy of both fuels (base: DF or RME and ethanol) Ω_E for engine operating conditions mentioned earlier.

5. 2. Objectives

The main objectives of this experiment were a follows:

- to investigate whether ethanol has any effect on combustion in CI engine fuelled with DF and RME as a base fuel,
- to measure emissions and efficiency in function of the ratio of ethanol energy to both fuels energy for different engine operating conditions,
- to determine the optimum ratio of ethanol to DF and RME from the point of view of emission and engine efficiency,
- to determine the optimum angle of beginning of the base fuel (DF and RME) injection from the point of view of emissions and efficiency for different engine operating conditions.

5. 3. Results and discussion

The best results with regards to emission were obtained for greenhouse gas and smoke. For example, emission of carbon dioxide for two base fuels vs. Ω_E is shown in Figs 8-11.

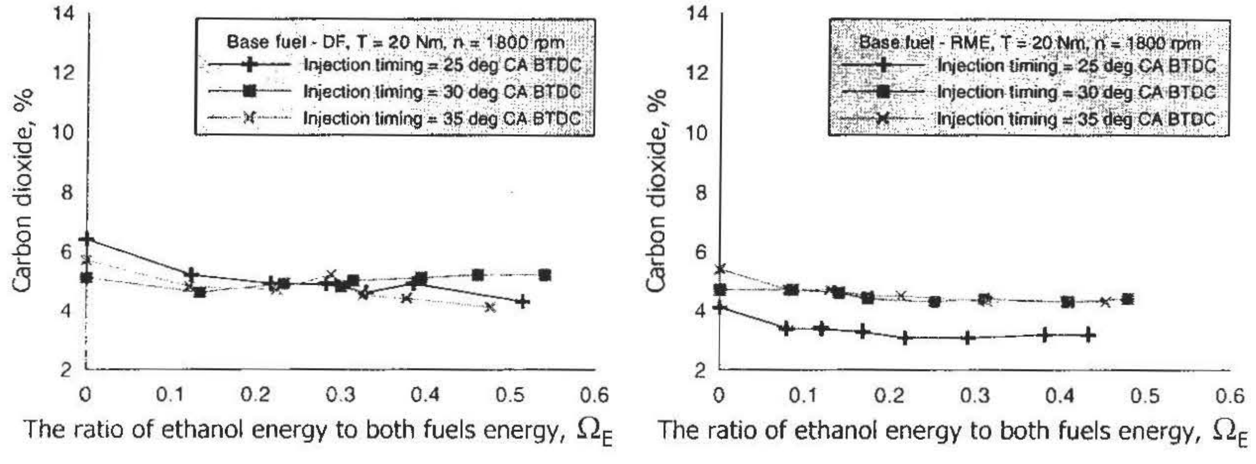

Fig. 8. Greenhouse gas emission vs. Ω_E at low load for engine fuelling with diesel fuel and ethanol and RME and ethanol

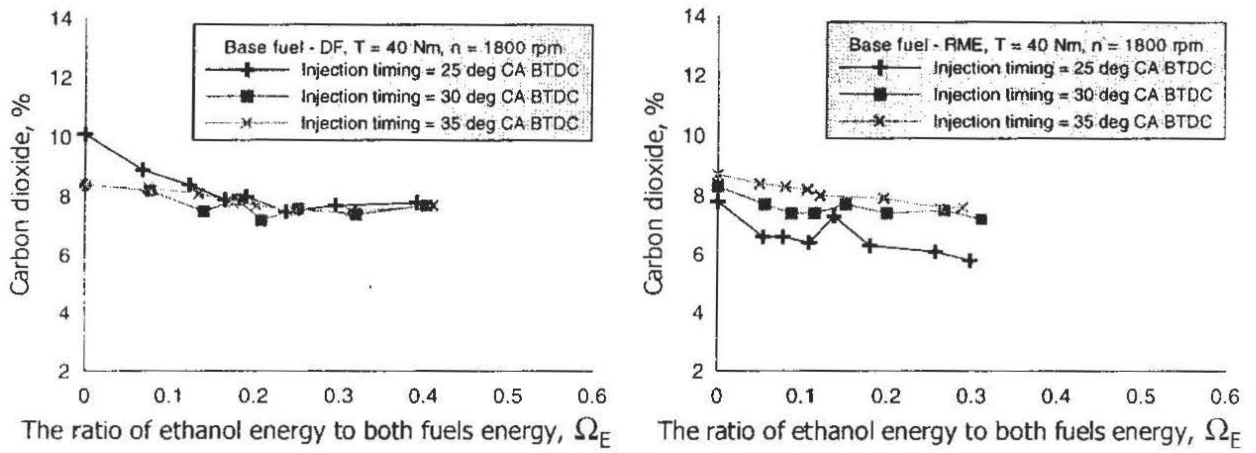

Fig. 9. Greenhouse gas emission vs. Ω_E at high load for engine fuelling with diesel fuel and ethanol and RME and ethanol

From these and other measurements it may be stated that, CO_2 emission:

- in comparison with the engine fuelled with DF, is lower for fuelling with RME,
- is higher at high load than at low load for any Ω_E for both DF and RME,
- decreases with increase of Ω_E for any injection timing and speed for both DF and RME.

The explanations of these results are as follows. RME has less carbon in the molecules than DF, hence lower CO_2 emission for RME fuel. Decrease of CO_2 emission is a result of higher Ω_E. Products of ethanol combustion contain less CO_2 and more H_2O. Higher CO_2 emission is a result of more fuel burnt at higher load.
Smoke emission is shown in Figs 10÷11.

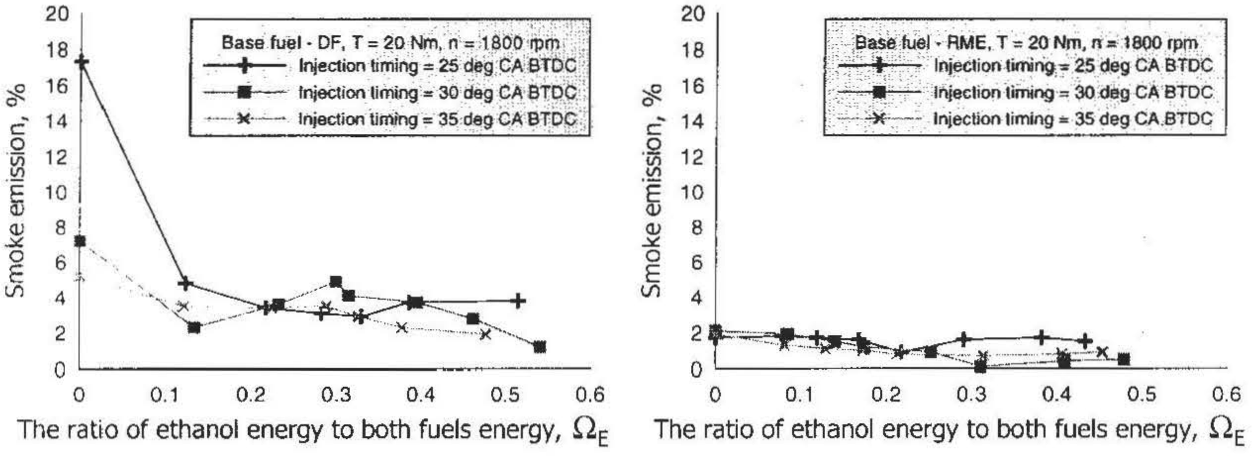

Fig. 10. Smoke emission vs. Ω_E at low load for engine fuelling with diesel fuel and ethanol and RME and ethanol

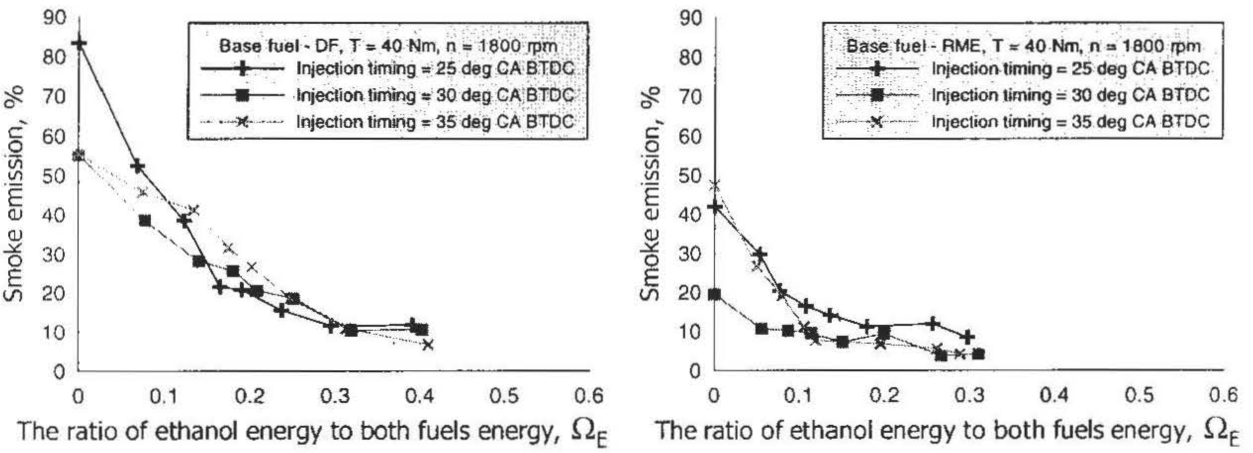

Fig. 11. Smoke emission vs. Ω_E at high load for engine fuelling with diesel fuel and ethanol and RME and ethanol

Smoke emission:

- in comparison with the engine fuelled with DF is lower for fuelling with RME at any load,
- at high load is higher than at low load for any Ω_E for both DF and RME,
- decreases with increase of Ω_E for any injection timing and at any load for both DF and RME,
- is the highest at the highest engine speed and for fuelling with neat DF or RME.

As far as other emissions are concerned, the results are as follows.

NO_x emission is lower for engine fuelling with RME than with DF. It depends strongly on the load, injection timing and the ratio of ethanol energy to both fuels energy Ω_E, for both base fuels (i.e. DF and RME):

- the higher the load, the higher the NO_x emission,
- the later injection of base fuel, the lower the NO_x emission,
- at the low load NO_x emission decreases with increase of the ratio of ethanol (due to lower temperature level being the result of higher energy of ethanol evaporation) and at high load – vice versa (more heat is evolved due to higher load and the influence of ethanol evaporation on temperature is relatively lower).

CO emission is generally higher for engine fuelling with RME than with DF and increases with ethanol addition. Only at part load for neat base fuel CO emission is comparable for both base fuels. The same tendency shows hydrocarbon emission.

6. Conclusions

From the carried out experiment the following conclusions may by drawn:

- Emission of the engine fuelled with diesel fuel and RME are similar; small advantage in smoke level and in NO_x emission for high speed and load for fuelling with rape oil methyl ester was obtained.
- Injection of ethanol into the inlet port reduces CO_2 emission, smoke and – in the case of high load – also NO_x and CO emissions for fuelling both with diesel fuel (DF) and rape oil methyl ester (RME).
- Ethanol fraction in both fuels (i.e. base fuel and ethanol itself) at low load may reach 50%, less at high load and is designated by diesel-knock.
- Optimum injection timing of DF and RME on account of minimum NO_x emission seems to delate injection – 25 deg BTDC.
- Optimum ratio of ethanol energy to both fuels energy for DF is 20% and for RME – 25%.
- More advantageous is fuelling the engine with rape oil methyl ester than with diesel fuel, on account of lower emission of CO_2, smoke, and in some operating conditions, also NO_x.
- Application of rape oil methyl ester as a base fuel will contribute to decrease the share of fossil hydrocarbon fuels in the fuel market.

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