

# Possible Applications of Bio-ethanol, RME & RFO-ME in Diesel Fuel

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## *Summary*

*The increase of petroleum prices, the continually decreasing sources of fossil fuels as well as the significant allotment of the traffic on the green house emission accent the necessity of the transition from fossil to the alternative fuels predominantly those originated from renewable sources.*

*The paper deals with the problems of alternative fuels in the course of which the main themes represent the application of RME (rapeseed oil methyl ester), RFO-ME (recycled frying oil methyl ester) and bio-ethanol into diesel fuel.*

*The results of laboratory and engine tests oriented on power output and exhaust emission characteristics using various portions of mentioned bio-components in diesel fuels are presented. In conclusions the positive and also the negative aspects of bio-component application in fossil diesel are reported and discussed.*

## **1. Introduction**

The idea to use vegetable oils as fuels for diesel engines is more than one hundred years old. It was published that one prototype of a new small diesel engine designed in accordance with the patent by Rudolf Diesel and built by French Otto Company presented at the World Exhibition in Paris in 1900 was operated on peanut oil. The engine was built for mineral oil and was used for the plant oil without any alterations being made. To be more precise five diesel engines were shown at the Paris Exposition and one of them was apparently operating on peanut oil (according to a biography of Rudolf Diesel by his son Eugen).

Due to the fact that petroleum based fuels were available at comparatively low prices for relatively long time period, except for some attempts at utilising renewable sources of energy during World War II, it was only in 1970s and early 1980s that the world-wide oil crises and a growing ecological awareness led to the rediscovery of plant oils as possible alternatives to hydrocarbon-based fuels.

There are several problems at the application of plant oils as diesel fuel which had to be overcome (high viscosity, poor fuel atomisation, tendency for thermal and/or oxidative polymerisation, formation of deposits on the injector nozzles, dilution and degradation of lubricating oil, sticking of piston rings, etc.). The mentioned problems can be solved either by adapting the engine to the fuel or by adapting the fuel to the engine (this way seems to be more convenient for automotive industry as well as for producers of renewable motor fuels).

Generally there exist four possible solutions: transesterification, pyrolysis, dilution with conventional petroleum-derived diesel fuel and microemulsification from which the

transesterification is the most common method and leads to monoalkylesters of vegetable oils and fats called biodiesel when used for fuel purposes.

A small pilot plant started its production of rapeseed oil methyl esters already in 1985 in Silberberg, Austria. The first industrial production plant for RME followed in 1991 (Aschach an der Donau, Austria) and in 1996 two large-scale industrial plants in Rouen, France, and Leer, Germany, documented the rapid growth of the biodiesel production industry.

Nowadays biodiesel has been in commercial use in several European countries (Austria, Czech Republic, Germany, France, Italy and Spain) and in some others (e.g. Slovakia) there are activities in biodiesel production and utilisation.

## **2. Experimental Results**

The application of three components - namely:

- rapeseed oil methyl esters (RME),
- recycled frying oil methyl esters (RFO-ME), and
- bio-ethanol

in petroleum-derived diesel fuel was tested by various laboratory and engine tests.

### **2.1 Laboratory Tests**

The base fuel (diesel) plus 3 times 6 additional fuel samples containing different portion of RME (2.5 till 30% V/V), RFO-ME (2.5 till 30% V/V) and bio-ethanol (2.5 till 20% V/V) have been prepared for laboratory and engine tests.

In the framework of laboratory tests the parameters as follows were measured for all the above mentioned samples:

- density at 15 °C,
- kinetic viscosity at 40 °C,
- flash point,
- cloud point,
- cold filter plugging point,
- oxidation stability,
- lubricity,
- cetane number, and
- distillation.

The results of laboratory tests are summarised in table 1, 2 and 3.

Table 1

Properties of diesel – rapeseed oil methyl ester (RME) blends

	Base Diesel	Base Diesel + RME					
		2.5	5.0	7.5	10	20	30
RME, % V/V	0	2.5	5.0	7.5	10	20	30
Density at 15 °C, kg/m <sup>3</sup>	840.4	841.5	842.6	843.7	844.7	849.2	853.7
Viscosity at 40 °C, mm <sup>2</sup> /s	2.685	2.717	2.755	2.792	2.829	2.990	3.159
Sulphur content, mg/kg	4.0						
Flash point, °C	77	79	78	79	78	79	81
Cloud point, °C	-8	-7	-7	-7	-7	-7	-7
CFPP, °C	-8	-10	-10	-9	-9	-9	-8
Oxidation stability, g/m <sup>3</sup>	1.4	1.6	2.9	89	266	894	1537
Lubricity (wsd 1.4), µm	359	322	279	261	256	244	241
Cetane number	51.8	52.3	52.9	53.5	54.3	55.5	58.0
Distillation, °C							
IBP	199	198	195	197	197	198	200
5 % V/V	214	215	212	213	215	216	218
10 % V/V	221	222	220	222	223	226	230
25 % V/V	235	236	238	239	241	246	255
50 % V/V	265	267	269	270	275	286	299
75 % V/V	298	302	306	307	312	322	328
90 % V/V	329	331	332	331	334	337	339
95 % V/V	345	346	346	343	346	349	351
FBP	357	357	354	352	353	352	353
Recovered at 250 °C, % V/V	38.1	36.4	34.8	33.9	32.3	26.0	20.9
Recovered at 350 °C, % V/V	96.3	96.1	95.1	96.0	94.7	93.9	93.8
Aromatics content, % m/m	31.5						
- monoaromatics	24.9						
- diaromatics	5.9						
- triaromatics	0.7						
- Polycyclic aromatics	6.6						

Table 2

Properties of diesel – recycled frying oil methyl ester (RFO-ME) blends

	<b>Base Diesel</b>	<b>Base Diesel + RFO-ME</b>					
RFO-ME, % V/V	0	2.5	5.0	7.5	10	20	30
Density at 15 °C, kg/m <sup>3</sup>	840.4	841.8	843.1	844.3	845.8	851.2	856.5
Viscosity at 40 °C, mm <sup>2</sup> /s	2.685	2.729	2.799	2.847	2.897	3.100	3.371
Sulphur content, mg/kg	4.0						
Flash point, °C	77	77	79	78	80	81	83
Cloud point, °C	-8	-7	-7	-7	-7	-7	-6
CFPP, °C	-8	-10	-8	-8	-8	-8	-8
Oxidation stability, g/m <sup>3</sup>	1.4	2.0	7.3	156	455	1676	2894
Lubricity (wsd 1.4), µm	359	270	241	229	217	206	201
Cetane number	51.8	52.0	52.3	52.9	53.4	54.4	55.2
Distillation, °C							
IBP	199	195	197	198	202	203	206
5 % V/V	214	213	218	218	219	221	224
10 % V/V	221	221	224	226	226	228	233
25 % V/V	235	236	239	239	241	246	254
50 % V/V	265	265	270	272	275	286	298
75 % V/V	298	301	306	309	312	322	329
90 % V/V	329	326	333	336	337	342	345
95 % V/V	345	339	347	349	350	353	352
FBP	357	353	355	354	353	353	353
Recovered at 250 °C, % V/V	38.1	37.5	34.7	33.5	32.8	27.0	21.4
Recovered at 350 °C, % V/V	96.3	97.5	95.6	95.0	95.0	94.2	93.1
Aromatics content, % m/m	31.5						
- monoaromatics	24.9						
- diaromatics	5.9						
- triaromatics	0.7						
- Polycyclic aromatics	6.6						

Table 3  
Properties of diesel – ethanol blends

	<b>Base Diesel</b>	<b>Base Diesel + Ethanol</b>					
Ethanol, % V/V	0	2.5	5.0	7.5	10	15	20
Density at 15 °C, kg/m <sup>3</sup>	840.4	840.9	839.7	836.0	840.7	839.7	831.2
Viscosity at 40 °C, mm <sup>2</sup> /s	2.685	2.675	2.526	2.168	2.509	2.352	2.047
Sulphur content, mg/kg	4.0						
Flash point, °C	77	33	16	14	14	13	13
Water content, mg/kg	35	47	59	70	82	105	129
Cold Flow Properties without Stabilizing Agent							
Cloud point, °C	-8	-8	-3	5	11	16	22
CFPP, °C	-8	-8	-10	-10	-8	-8	-8
Cold Flow Properties with Stabilizing Agent							
Cloud point, °C	-8	-8	-7	-7	-6	0	5
CFPP, °C	-8	-8	-10	-9	-8	-8	-8
Stabilizing Agent, % V/V	0	0.3	0.5	0.80	1.7	2.5	3.0
Lubricity (wsd 1.4), µm	320	332	345	360	370	380	390
Lubricity improver, mg/kg	120	180	220	260	290	350	420
Cetane number - without C.I.	49.9	49.5	47.6	46.1	44.7	40.7	36.6
Cetane improver (C.I.), mg/kg <sup>x)</sup>	120	550	1 300	2 300	3 700	7 000	11 000
Cetane number - with C.I.	51.8	51.9	51.9	51.7	51.6	51.5	51.6
Distillation, °C							
IBP	199	116	80	78	77	76	66
5 % V/V	214	215	212	79	81	80	77
10 % V/V	221	222	218	207	2069	82	77
25 % V/V	235	236	234	229	235	207	79
50 % V/V	265	265	265	255	264	248	238
75 % V/V	298	299	299	293	300	287	283
90 % V/V	329	330	331	322	333	325	316
95 % V/V	345	346	349	337	354	344	334
FBP	357	356	358	351	356	353	345
Recovered at 250 °C, % V/V	38.1	37.1	38.5	44.4	39.3	51.2	57.8
Recovered at 350 °C, % V/V	96.3	95.9	95.2	98.0	94.3	96.2	98.0
Aromatics content, % m/m							
- monoaromatics	31.5						
- diaromatics	24.9						
- triaromatics	5.9						
- Polycyclic aromatics	0.7						
	6.6						

<sup>x)</sup> Dosage of the cetane improver was set to obtain the cetane number 51 - 52

## 2.2 Engine Tests

After finishing the above presented laboratory tests the prepared fuel samples were tested as for the power output and exhaust emission characteristics. Also the measurements of acceleration were carried out.

The engine tests were performed in engine testing laboratory using passenger car (1896 ccm displacement, SDi diesel engine, mechanical gear box) and chassis dynamometer.

All the performed measurements are graphically illustrated in figures 1 to 9.

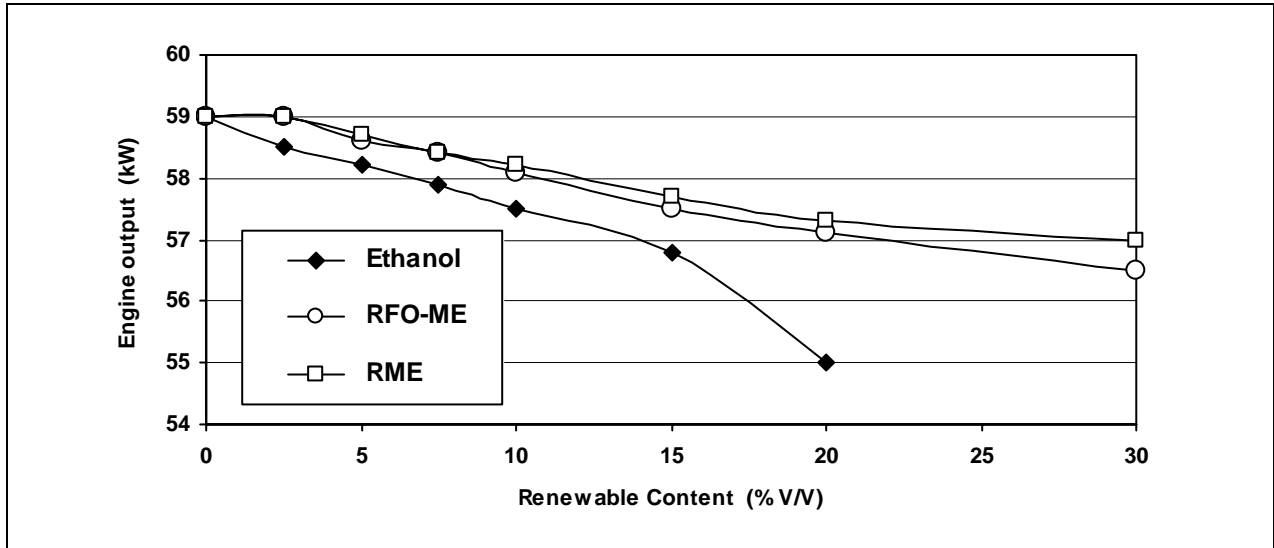


Fig. 1 Effect of renewable content on engine output

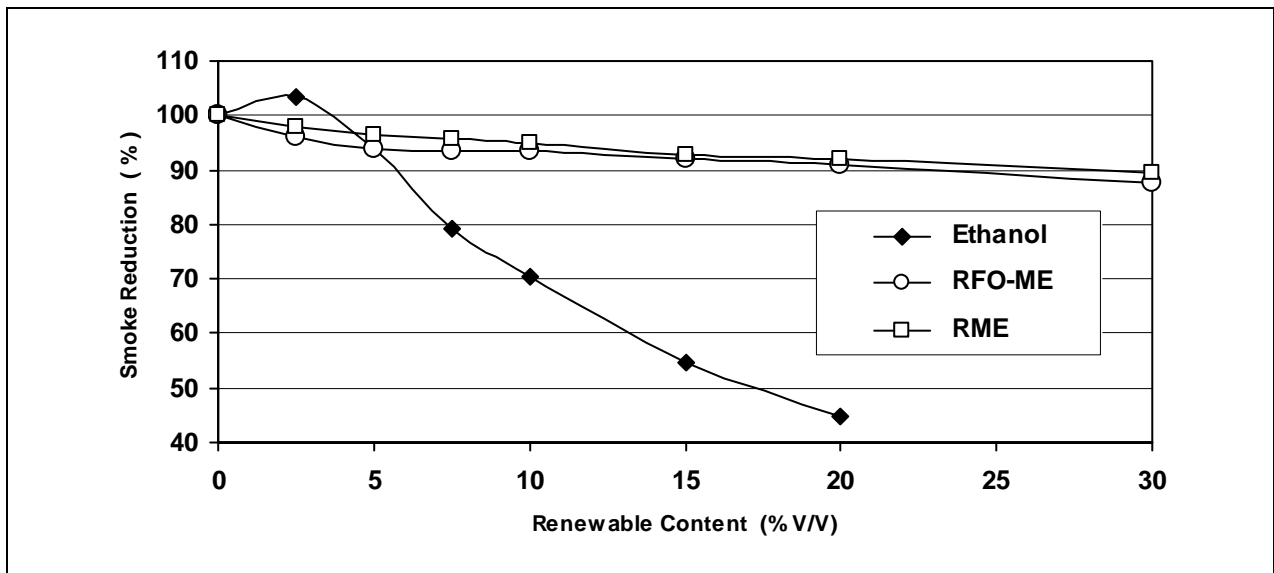


Fig. 2 Effect of renewable content on smoke reduction (base diesel fuel = 100%)

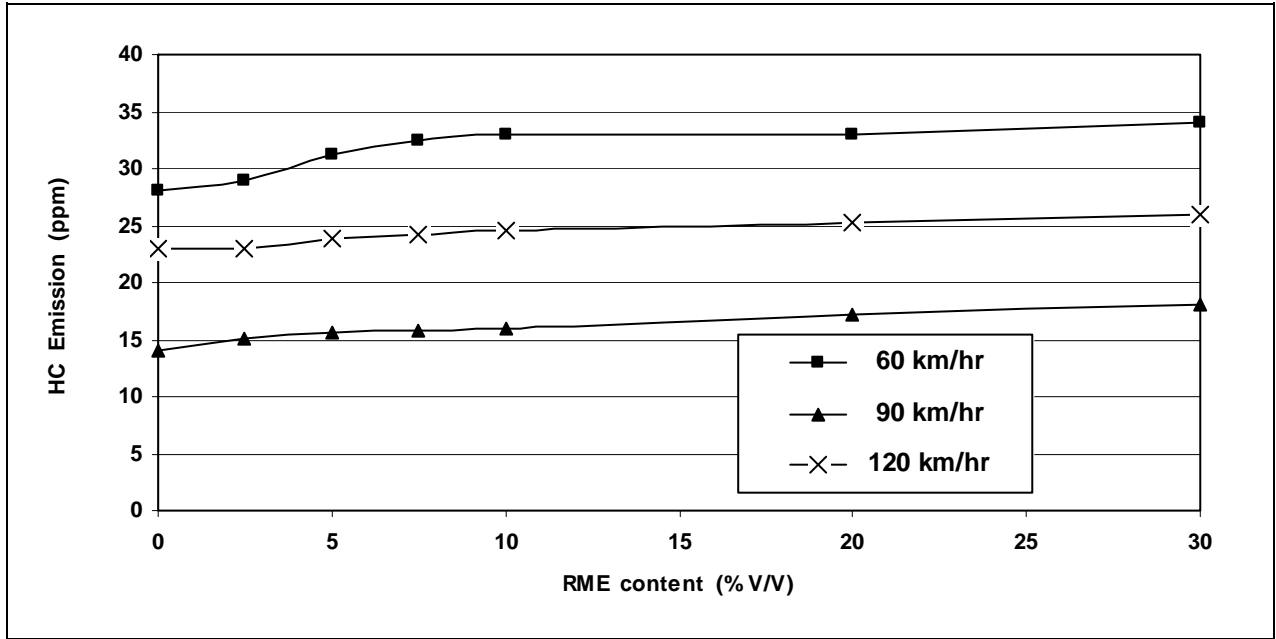


Fig. 3 Effect of RME content on hydrocarbon emission at constant speeds

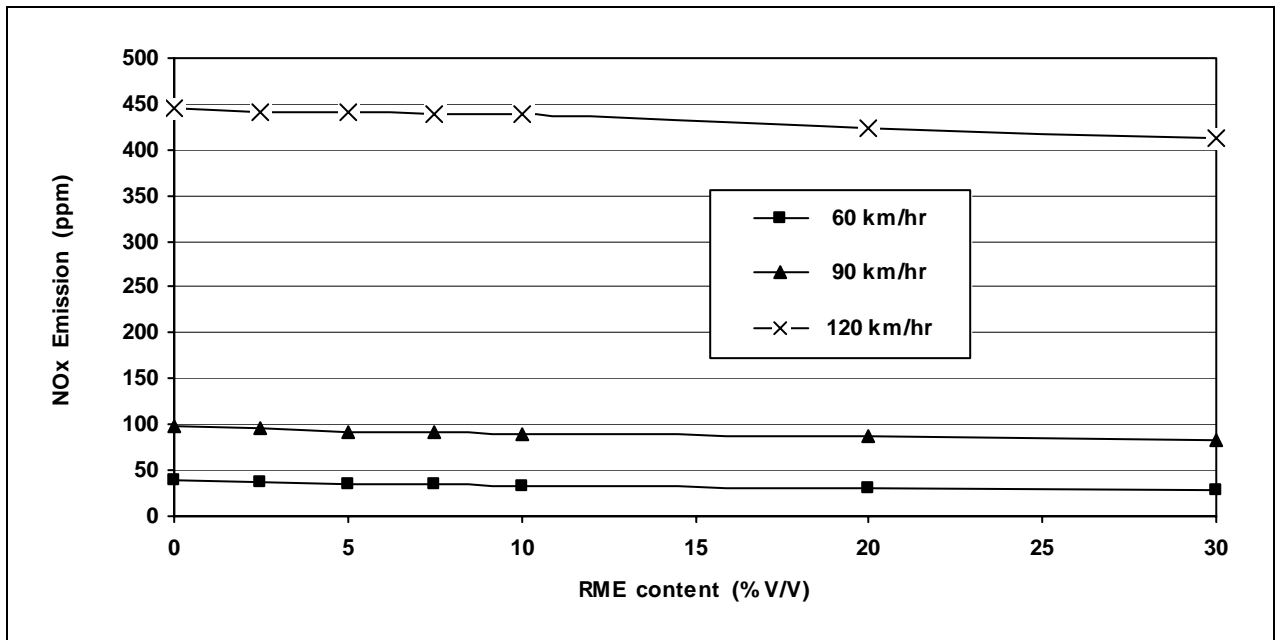


Fig. 4 Effect of RME content on nitrogen oxides emission at constant speeds

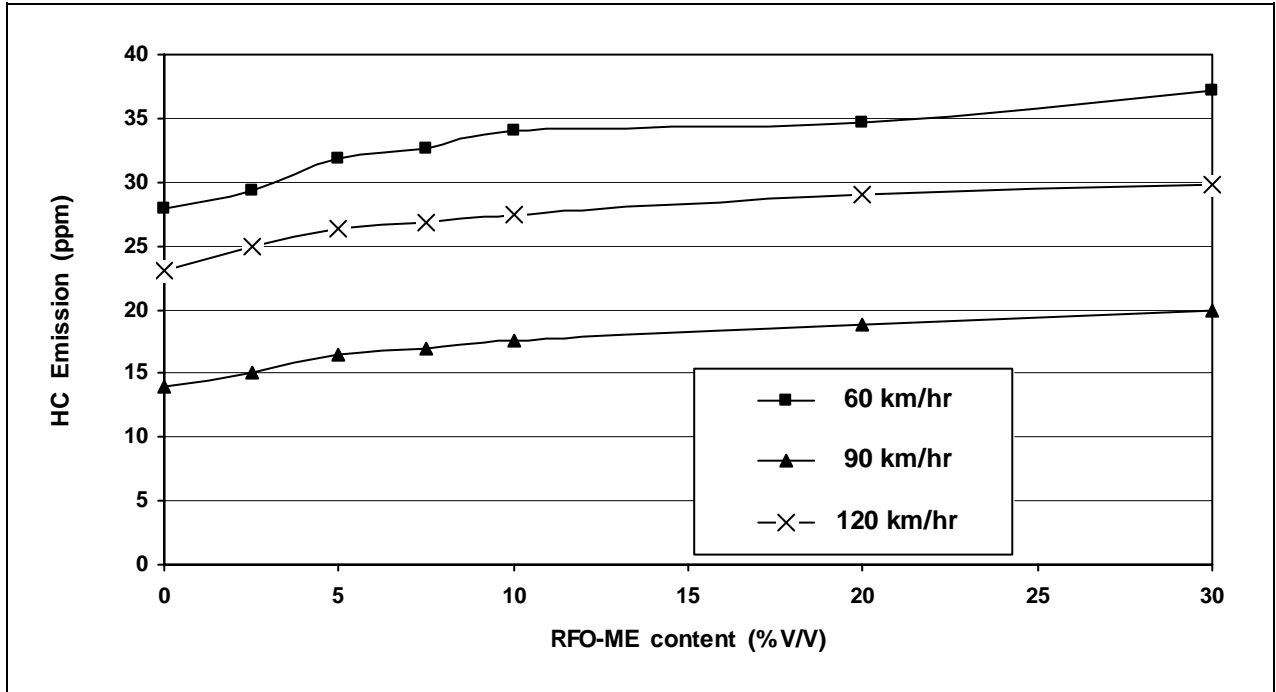


Fig. 5 Effect of RFO-ME content on hydrocarbon emission at constant speeds

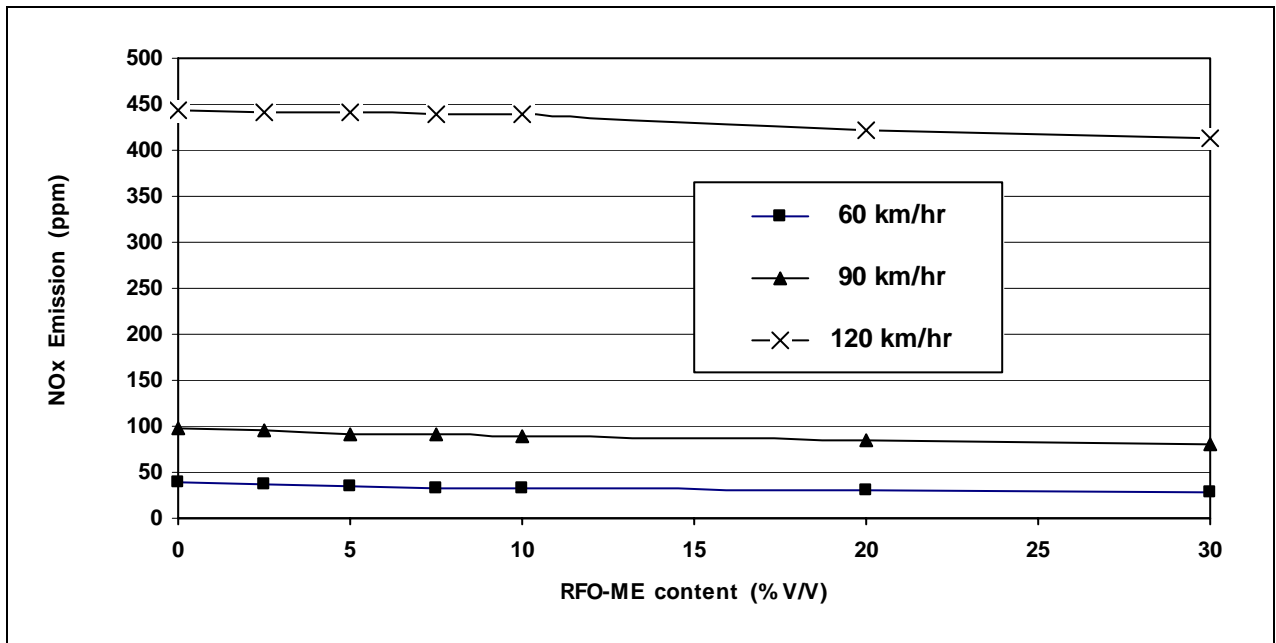


Fig. 6 Effect of RFO-ME content on nitrogen oxides emission at constant speeds

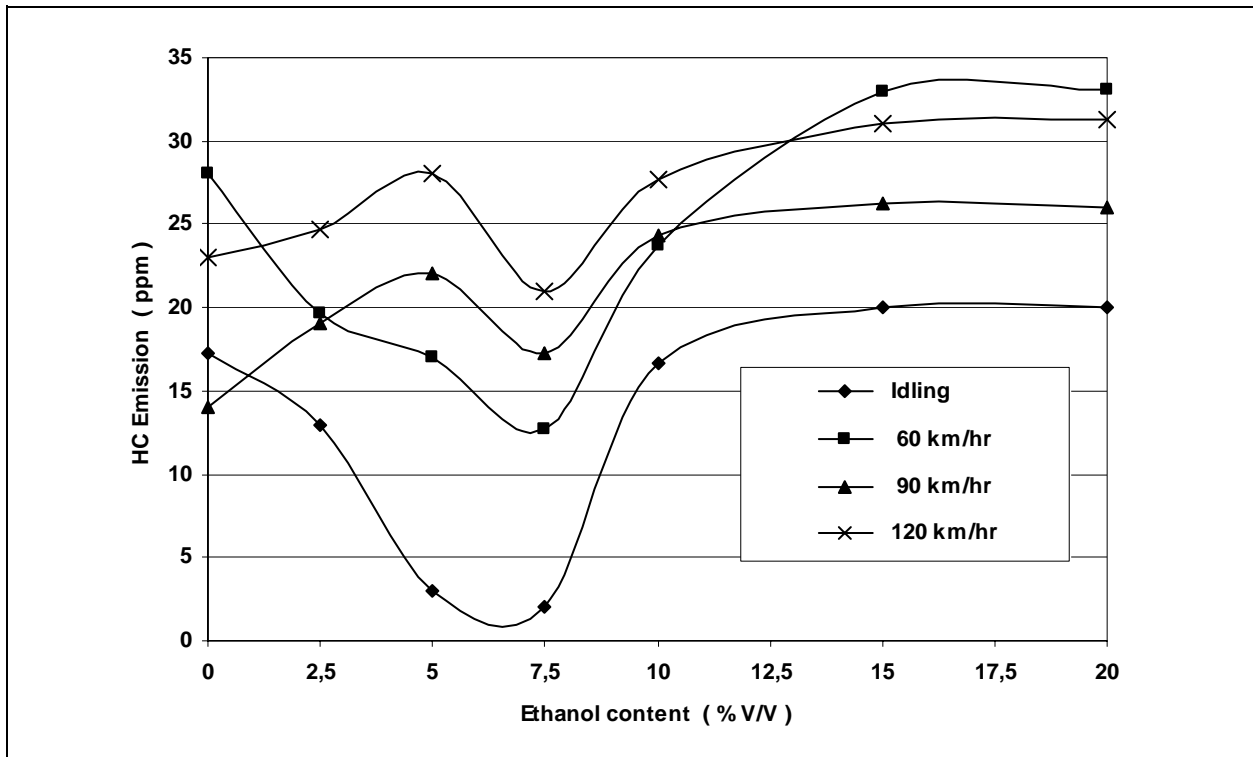


Fig. 7 Effect of ethanol content on hydrocarbon emission at idling and constant speeds

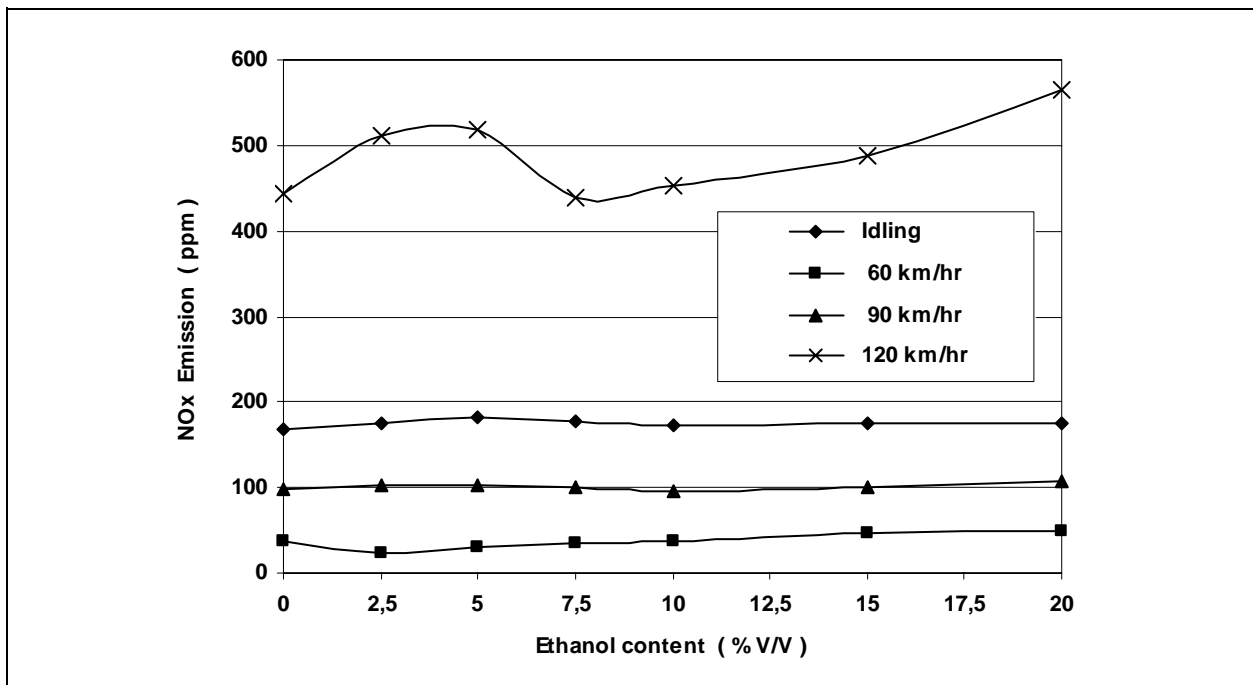


Fig. 8 Effect of ethanol content on nitrogen oxides emission at idling and constant speeds

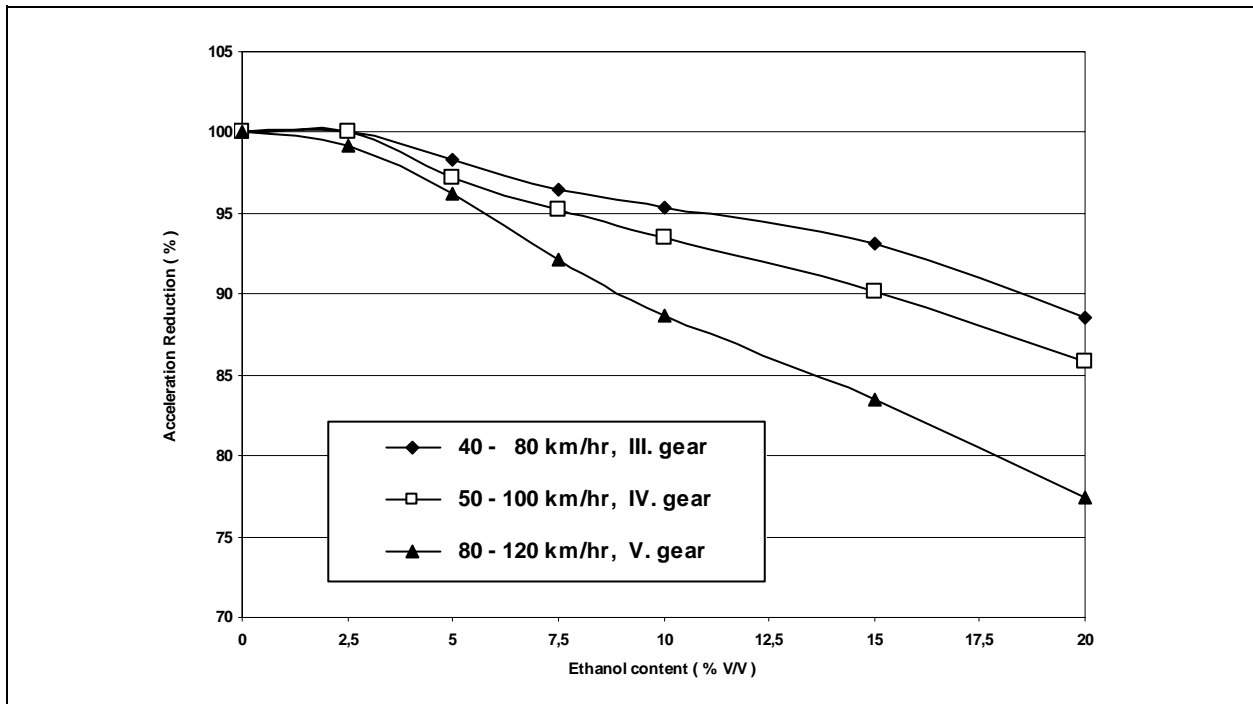


Fig. 9 Effect of ethanol content on acceleration reduction (base diesel fuel = 100%)

### 3. Discussion

#### 3.1 Laboratory Test Results

As documented in tables 1 and 2 the growing content of RME and RFO-ME has positive impact on the parameters as follows:

- lubricity,
- cetane number.

Negative impact was measured at:

- density at 15 °C,
- kinetic viscosity at 40 °C,
- oxidation stability.

Practically no or very slight differences were observed at flash point, cloud point, cold filter plugging point and distillation.

The results from bio-ethanol applications (see table 3) are rather complicated and not easy to be commented.

The growing bio-ethanol content drastically reduces flash point and has clearly negative impact as for the lubricity and water content. Also negative role plays ethanol content at cold flow

properties. The negative impact as for lubricity and cold filter plugging point can be compensated by proper application of lubricity improver and stabilising agent respectively.

The values of viscosity, density and distillation have their local minima at the ethanol content of approx. 7.5% V/V. This phenomenon is also documented in figures 10 and 11.

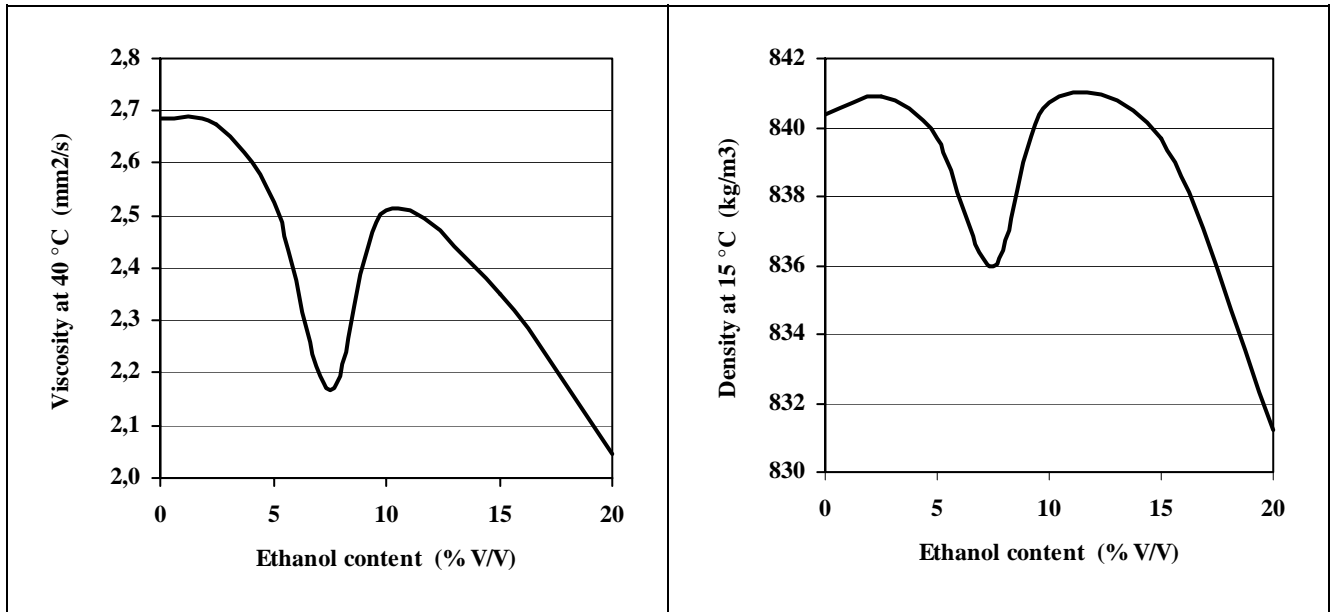


Fig. 10 Effect of ethanol content on viscosity and density of ethanol – diesel mixtures

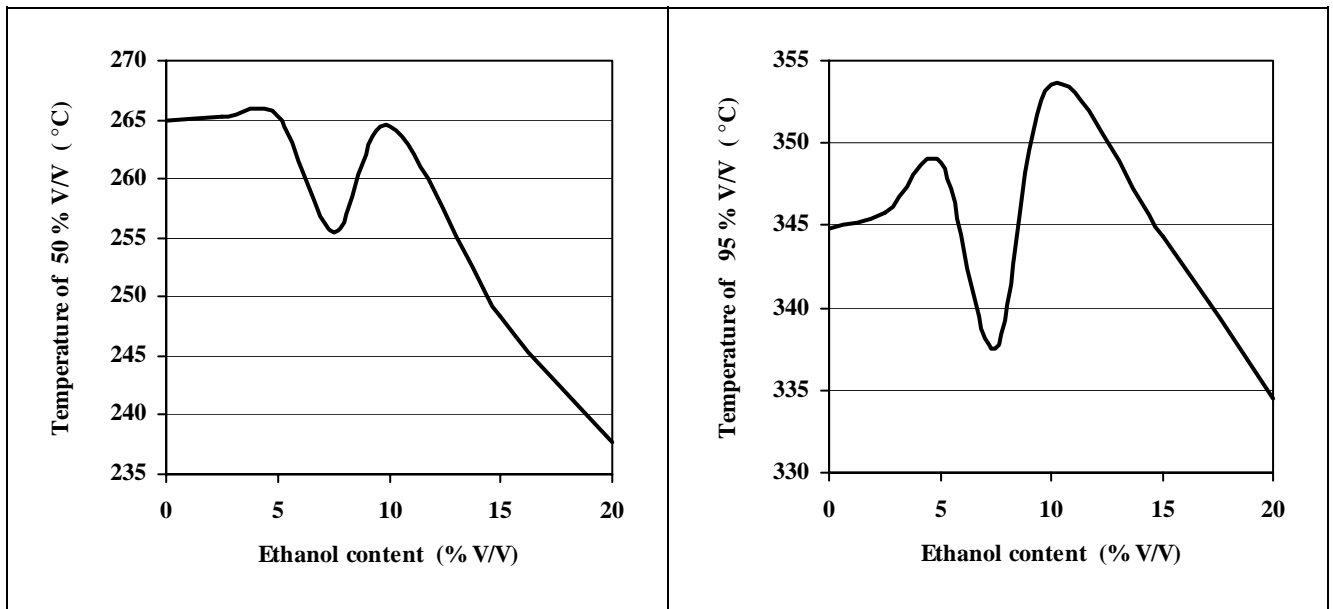


Fig. 11 Effect of ethanol content on distillation of ethanol – diesel mixtures

## **3.2 Engine Tests Results**

### **3.2.1 Power Output and Torque Measurement**

As documented in Fig. 1 the presence of RME and RFO-ME (up to 20% V/V) in fossil diesel fuel has only slight impact on power output (max. 3.5%), whereas the concentration of ethanol by 20% V/V caused the power output decrease by approx. 7.0%. The measurements of torque showed practically the same tendency.

### **3.2.2 Exhaust Emission Characteristics**

Fig. 2 illustrates the smoke reduction. It can be stated, that the application of RME and RFO-ME results in slight decrease of smoke, but at the ethanol content of 20% V/V the reduction of smoke is higher than 50%.

As illustrated in figures 3 to 6 the application of RME has no significant effect as for the HC and NO<sub>x</sub> emissions. At the application of RFO-ME the HC concentration in exhaust gasses is slightly higher with the growing RFO-ME content, whereas the NO<sub>x</sub> emissions at constant speeds of 60, 90 and 120 km/hr remain practically constant.

The exhaust emission measurements performed with blends of diesel and ethanol (Fig. 7 and 8) show that the influence of ethanol content on NO<sub>x</sub> emission is negligible but as for the HC emissions there is a clear minimum at the ethanol content of approx. 7.5% V/V measured at constant speeds and idling as well what very good corresponds with the phenomenon observed at laboratory tests described in the paragraph 3.1 and illustrated in Fig. 10 and 11.

The impact of ethanol content on accelerate decrease is presented in Fig. 9. It can be stated that the ethanol content of 20% V/V causes the acceleration regress by 12 to 23% depending on measured speed range and applied speed gear.

## **4. Conclusions**

### **4.1 Laboratory Tests**

- the presence of RME or RFO-ME in fossil diesel has some positive (better lubricity, higher cetane number) and some negative (higher density and higher kinetic viscosity) aspects, but the most negative impact was observed as for the degradation of oxidation stability (predominantly when RFO-ME is applied),
- the presence of bio-ethanol drastically reduces flash point and lubricity, on the other hand the positive impact on kinematic viscosity can be observed.

### **4.2 Engine Tests**

- concentration of RME and RFO-ME up to 20% V/V leads to the power output and torque regress by approx. 3.5%, whereas the same concentration of bio-ethanol causes the decrease by approx. 7.0%; also the decline of acceleration at ethanol application is considerable high (12 to 23%),

- the exhaust emission characteristics document the positive impact of the tested components on smoke reduction,
- no significant changes were observed as for NO<sub>x</sub> emissions at the application of presented components,
- as the most interesting point can be introduced the fact that HC emissions show an expressive minimum when ethanol is applied (at approx. 7.5% V/V); this phenomenon is in accordance with the results of laboratory tests concerning density, kinetic viscosity and distillation.

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