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Full Length Research Paper

Properties of fossil diesel oil blends with ethanol and FAME as fuels for diesel engines

Andrea Kleinová* and Ján Cvengroš

Faculty of Chemical and Food Technology, Slovak University of Technology (STU), Bratislava, Slovak Republic.

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Ethanol is an attractive oxygenate not only for gasolines but also for diesel fuels. The paper presents the results of the study of stability of blends fossil diesel oil-ethanol, at the temperature of -10°C. Low-temperature phase stability was significantly influenced by the presence of water in the blend. The stability of blend was increased by the addition of FAME. The ternary mixture fossil diesel oil – FAME – ethanol was stable at -10°C, if the ratio FAME: ethanol (0.70% w/w of water) was higher than 2. Selected ternary blends with the content of bio-components 7 and 10% v/v were used in performance and emission tests with two types of testing engines. The presence of oxygenates had no negative influence on performance parameters of the engines and they positively influenced the emissions, especially opacity. Except of the flash point, the fuel parameters of blended fuels were not impaired and excellent lubricity was achieved.

Key words: Ethanol – diesel oil blends, diesel oil – FAME – ethanol blends, oxygenates, performance and emission tests, opacity.

INTRODUCTION

Interest in bioethanol (EtOH) as attractive extender of EtOH and fossil diesel oil blends utilizable as a fuel for diesel engines started in the eighties during the petroleum crisis. It was shown that EtOH as typical component of liquid fuels for ignition engines can be used also in a blend with fossil diesel oil (FDO) in standard diesel engines. The utilization of EtOH as a fuel component for diesel engines is discussed in detail in comprehensive study (Hansen et al., 2005). Due to high price of EtOH, this type of fuel was considered as an alternative only for crises periods. Recently, the economic situation has changed in favor of EtOH, which is actually able to compete with the standard diesel oil. Despite the fact that after EtOH addition to the FDO the characteristics of blended fuel are generally less favorable compared to FDO alone, there exists serious economic pressure to use EtOH also as a component of diesel fuel. This applies especially for the European region with preferential interest in diesel fuels and lesser interest in gasoline fuels. EtOH is attractive as a fuel from renewable sources as well as oxygenate with positive influence on emissions, especially on particular matters.

Suitability of particular fuel for diesel engines is influenced by several aspects. Addition of EtOH to FDO influences properties of the resulting fuel blend as are the phase stability, viscosity, lubricity, power content and cetane number (CN). Corrosiveness and safety aspects characterized by flash point and flammability are also important.

Fuel viscosity and its lubricity play important role in lubrication of high-pressure fuel injection pump. Addition of EtOH to the FDO decreases viscosity (Barabas et al., 2010) and lubricity (Lapuerta et al., 2010a) of fuel blend. The blend of 10% of dry EtOH in FDO has viscosity approaching the minimum value requested by the standard (Wrage and Goering, 1980). Lubricity tests in the system FDO – EtOH using HFRR method according to EN 12156-1 are scarce (Lapuerta et al., 2010a, b). Reported higher corrosiveness of blended fuel FDO – EtOH should be connected with highly hygroscopic

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*Corresponding author. E-mail: andrea.kleinova@stuba.sk. Tel: +421 2 59325538. Fax: +421 2 52926032.

Abbreviation: BSFC, Brake specific fuel consumption; **CFPP,** cold filter plugging point; **CN,** cetane number; **CO,** carbon monoxide; **EtOH,** ethanol; **FAME,** fatty acid methyl esters; **FDO,** fossil diesel oil; **HC,** hydrocarbons; **NOx,** nitrogen oxides; **PM,** particular matter.

behavior of EtOH.

Power content of the FDO – EtOH blend decreases by 3% for each 5% v/v of added EtOH and does not represent a key problem (Wrage and Goering, 1980). Decreased power output can be caused also by pump leakage due to lower viscosity of the fuel. Typical CN of FDO ranges from 45 to 50. The CN of EtOH is estimated to be in the range between 5 and 15. It is therefore recommended to apply CN improvers so that CN of fuel blend reaches the prescribed range. Possible additive is triethylene glycol dinitrate (Meiring et al., 1983).

Low flash point of the blended fuel FDO–EtOH represents a serious problem. Blends of EtOH and FDO have the flammability practically identical to that of EtOH regardless of the EtOH content. Flash point of 12℃ classifies FDO – EtOH blends as flammable liquids of Class I, while FDO itself belongs to Class III (flash point over 56℃). This applies more stringent requirements on storage and increased safety distances from storage tanks.

During emission tests, substantial decrease of the content of particular matter (PM) by 20 to 27% was monitored at 10% of EtOH addition to the FDO (Spreen, 1999). Other emission components such as CO, HC, NOx were reported by some authors to achieve substantial decrease (Kass et al., 2001), while other authors reported the values ranging in both directions comparing to standard FDO (Schauss et al., 2000; Rakopoulos et al., 2008), depending on speed and load of the engine but still well below the prescribed emissions limit.

EtOH solubility in FDO depends on temperature and water content in the blend (Fernando and Hanna, 2004). Dry EtOH with water content less than 0.20% w/w is at higher temperatures completely miscible with FDO. At temperatures below 10℃, there is a separation of components and formation of two phases at a rate dependent on water content in the system (Lapuerta et al., 2007). Separation can be avoided by addition of an emulsifying agent to keep the emulsion of EtOH in FDO stable or by addition of a co-solvent as a bridging agent for homogeneous blending (Hansen et al., 2005). Approximately, 2% of a surfactant was required for every 5% of aqueous EtOH (5% of water) added to FDO to keep the micro-emulsion stable (Moses et al., 1980). Tetrahydrofurane or ethyl acetate was found as effective co-solvents to prevent phase separation (Lechter, 1983). The consumption of co-solvent increases with increasing water content and decreasing temperature. At 0℃, full miscibility ratio for ethyl acetate to dry EtOH was 1:2. Presence of aromatics in FDO increases EtOH solubility as well as the effects of co-solvents and emulsifying agents (Gerdes and Suppes, 2001).

Fatty acids methyl esters (FAME) can also be used as possible co-solvents preventing separation of FDO – EtOH blends (McCormick and Parish, 2001). The combination of these two oxygenates may help to balance their less favorable properties. EtOH may be expected to improve the low temperature filterability, while high CN of FAME can compensate its decrease in FDO – EtOH blend. It has been proved that engine performance with such fuel blends did not differ significantly from engine performance with FDO (Ali et al., 1995a, b). The blends containing 10, 20 and 30% w/w of EtOH and 5, 10 and 15% w/w FAME, respectively, were studied by Chen et al. (2008) without providing any information on their phase stability. Significant reduction of smoke and PM was recorded but the used high percentage of oxygenates are hardly applicable in praxis from the economical and capacity reasons. In other study, a blend of 20% v/v of EtOH in FAME was added to FDO as an oxygenated additive at the levels of 15 and 20% v/v, respectively (Shi, 2005). PM, CO and HC decreased with increasing oxygenate content but NOx emissions increased.

In the current study, we dealt with the impact of EtOH addition to the FDO with the aim to find real and practically applicable proportion with suitable fuel properties. The influence of FAME as a co-solvent for increasing the phase stability at low temperatures and also as a lubricity enhancer is presented. The role of the influence of water content in binary and ternary blends of FDO, EtOH and FAME on the phase stability is also searched. We discuss the results from low-temperature phase stability tests as well as some performance and emissions characteristics of FDO – FAME – EtOH blended fuels.

EXPERIMENTAL

Materials

FAME was prepared by standard two-step alkali transesterification (Cvengroš and Považanec, 1996) of refined rapeseed oil with the acid value of 0.2 mg KOH/g. Crude FAME were finally treated by washing (1% w/w of water), centrifugation and filtration. EtOH with water content 0.70% w/w and 0.20% w/w containing denaturizing agents were obtained from Slovnaft VURUP, Bratislava, Slovak Republic. Winter, additive- and sulphur-free diesel oil was delivered by the company Slovnaft VÚRUP Bratislava, Slovak Republic. Low-temperature properties of the used FDO were modified by adding commercial additives, detergent (200 ppm) and depressant (300 ppm). Parameters of the used diesel oil without additives are summarized in Table 1. Alkanolamide-based additive for adjustment of anticorrosion properties LUBOL 210D, exhibiting also detergent effect and ability to bind water was supplied by Lubocons Chemicals, Stupava, Slovak Republic.

Preparation of fuel blends

FDO, EtOH and FAME, respectively, were simply blended to form mixture with defined ratio of individual components. EtOH content ranged from 2 to 6% w/w and FAME content from 6 to 10% w/w. Two sets of measurements were performed utilizing 1% w/w of LUBOL 210D.

Table 1. Characteristics of fossil diesel oil (FDO).

Characteristic	Unit	Value	Method
Density at 15 °C	kg m^{-3}	832.6	EN 12185
Viscosity at 40 °C	mm^2 s^{-1}	2.376	EN 3104
Cetane index		50.7	EN 4264
Cetane number		50.6	EN 5165
Water content	mg kg^{-1}	26.2	EN 12937
Flash point	°C	70	EN 2719
CFPP	°C	-30	EN 116
Lubricity	µm	605	EN 12156-1

CFPP – Cold Filter Plugging Point.

Table 2. Characteristics of used engines.

Type of engine	2.5 UI	MD UR IV
Cylinder number	5	4
Bore (mm)×Stroke (mm)	81×95.5	110×128
Volume (L)	2.5	4.8
Compression ratio	19.5:1	18.8:1
Maximal power output (kW/rev)	128/3500	80.8/2200
Maximal torque (N m/rev)	400/2000	407/1480
Injection pressure (bar)	2050	900

Laboratory tests

The model blends of FDO containing EtOH (0.7% w/w of water) and FAME were tested according to the testing methods prescribed by the standard EN 590. For testing the phase stability at low temperatures, the samples were cooled down to -10°C in liquid bath and kept at this temperature for 24 h. After this period of time, their appearance at this temperature was visually evaluated - cloudiness and the presence of new liquid phase, the presence of the new liquid phase being of key importance. This methodology was considered as sufficient for present purposes. In addition, we do not know other options for evaluation of phase stability at low temperatures. The temperature of -10°C was selected with respect to CFPP -10°C. According to EN 590 this CFPP value is actual during three quarters of a year, while -20°C only 3 winter months.

Testing engines

To test blended fuels with bio-component content of 7 and 10% v/v, a passenger car VW Touareg R5 2.5 unit injection (UI) System, engine code AXD, year of production 2007, was used. Basic engine characteristics of the used all-wheel drive car are given in Table 2. The engine is four-stroke inline five cylinder (R5) Turbocharged direct injection (TDI) turbodiesel, gear-driven single overhead camshaft (SOHC), swirl-inducing intake ports, high pressure fuel injection (UI). The engine is liquid cooled and supercharged, with intercooler of compressed air. It has 10 valves total, hydraulic bucket tappets with automatic valve clearance compensation, 5-hole injection nozzle, the hole diameter 0.35 mm.

The measurements were carried out also on a 4-cylindrical engine MD UR IV 8004.000, whose parameters are shown also in Table 2. Diesel engine UR IV is four-stroke, four-cylinder-in-line OHV, with direct fuel injection. The engine is liquid cooled and supercharged, without intercooler of compressed air. 5-hole injection nozzle, the hole diameter 0.35 mm. The engine is used as a power unit for agricultural and forest tractors, building and ground machinery, electricity generating stations, water pumps and other industrial devices.

Performance and emission tests, fuel consumption measurements

Performance measurements on testing engine 2.5 UI were carried out using the chassis dynamometer MAHA LPS 2000 (MBH Haldenwang/Allgäu, Germany). Emission measurements were performed with an exhaust gases analyzer MAHA MGT 5 by means of the emission determination at steady-state mode during idle running and the constant speeds of 60, 90 or 120 km/h. The analyzer operated on the principle of infrared spectroscopy. The contents of CO, CO_2, and HC were determined based on selective absorption of each gas in the proper range of IR radiation. O2 and NOx measurements were carried out electrochemically using the appropriate sensor. Diesel engine opacity determination was performed by the method of free acceleration with an opacitometer AVL DiSmoke 435. The test is based on the evaluation of the light beam absorption and scattering by exhaust gas in comparison to the standard. Opacity is expressed as 1 to 100% HSU (Hartridge Smoke Unit). Aldehydes were determined by sucking the volume of combustion products measured by gasometer through detection tube, and determined as described in (Potter and Karst, 1996; EPA, 2006). Fuel consumption measurements were done by the weighting of tested fuel samples at constant speed regime of 60, 90 or 120 km/h and time intervals of 60, 40 and 30 s. The obtained results in g/min were then converted to g/kW h on the basis of

Table 3. Phase stability of the FDO – EtOH blends at -10 °C.

FDO (% w/w)	EtOH (% w/w)		LUBOL 210D (% w/w)	phase stability at -10°C	
	0.7% H_2O	0.2% H_2O		EtOH (0.7% H_2O)	EtOH (0.2% H_2O)
98	2	2	-	Unstable	Stable
96	4	4	-	Unstable	Unstable
94	6	6	-	Unstable	Unstable
97	2	2	1	Unstable	Stable
95	4	4	1	Unstable	Stable

measured power at given constant speeds.

During the measurement of the performance and emission characteristics with the MD UR IV engine, the regulated emissions such as CO, HC were measured continuously using a certificated measuring technique according to EEC requirements. Sampling of gas from the exhaustion pipe of the engine was carried out according to EEC 49 recommendations for regulated and non-regulated emissions. The samples for determination opacity were taken separately with a different probe. The measurements were carried out in a steady state mode after stabilization of the temperature of exhaust gases. The selection of modes was carried out on a basis of the EEC modes, where the most relevant is the mode with the maximum output and the maximum torque. In order to better demonstrate the influence of alternative components of the fuel on the content of aldehydes, the mode of maximum engine revolutions at half engine load was selected. The engine is of older conception and according to the former regulations it was adjusted to opacity value max. 60% HSU (Hartrige Smoke Units). The engine was decelerated with the use of a dynamometer MEZ Vsetín DS 1002-4/V.

The results of individual tests are summarized in the corresponding Tables. The values of the parameters given in the Tables represent the average of five measured values. Other determinations of respective parameters were carried out by standardized procedures.

RESULTS AND DISCUSSION

Phase stability at low temperatures

Phase stability of the FDO – EtOH mixture at -10°C

EtOH with water content 0.2 and 0.7% w/w was used in phase stability tests in a two-component system FDO – EtOH. The criterion for stability evaluation was the presence or absence of cloudiness and formation of a new liquid phase. The cloudiness may be related to achievement of the cloud point and does not necessarily represent phase instability. After temperature rising, cloudy sample clears out without any consequences. The decisive indication of the phase instability is then the formation of a new liquid phase. The new liquid phase has lower density and is placed over the non-polar phase. Similar long-term visual assessment of phase stability was performed by Jimenez et al. (2010) in the temperature range of -18 to 30°C. This methodology was considered sufficient for these purposes. Lapuerta et al. (2010a) studied the stability of alcohols – FDO blends in the temperature range from -10 to 40°C using optical equipment Turbiscan, but without any detailed information about the measurement methodology.

The results of the tests are summarized in Table 3. It is shown that in the system FDO – EtOH with the water content 0.70% w/w there exists no suitable FDO – EtOH ratio, which would exhibit long term phase stability at -10°C. Close to this goal comes the system containing also 1% w/w of the LUBOL 210D additive at the FDO – EtOH ratio 97:2. If EtOH with lower water content 0.20% w/w is used, the phase stability of the two-component blend will be increased. The FDO blend with the addition of 2% w/w of such EtOH is stable at the studied temperature of -10°C. The system containing 4% w/w of EtOH with the water content 0.20% w/w is already phase unstable. The effect of the LUBOL 210D is positive; it contributes to phase stability in the case of the blend FDO – EtOH – LUBOL 95:4:1 (water content in EtOH 0.20% w/w).

Phase stability of FDO – FAME – EtOH blend at -10°C

In the study of phase stability of the system FDO – FAME – EtOH, with FAME as a co-solvent, EtOH with higher water content (0.70% w/w) was used, as at lower EtOH contents (0.20% w/w of water) the systems were stable without co-solvent. The results are summarized in the Table 4, and show that the FAME addition increases the stability of blended fuels also in the case when increased amount of water is present in the blends. The mixtures with the EtOH portion 2, 4 and 6% w/w and with the FAME portion 6, 8 and 10% w/w were used for the measurements. The systems are stable at the EtOH content up to 4% w/w and simultaneously at the FAME: EtOH ratio higher than 2. If the ratio is less than 2, the phase stability at -10°C is impaired.

Physico-chemical properties of blended fuels

The attention has been paid to selected properties of blended fuels, where there the strongest influence of the

Table 4. Some physico-chemical properties of FDO – FAME – EtOH blends, water content in EtOH 0.7% w/w.

FDO (% w/w)	FAME (% w/w)	EtOH (% w/w)	CFPP (°C)	nu ((40°C) (mm^{2}s^1)	ρ (15°C) (kg m^{-3})	Phase stability at -10°C	Lubricity (µm)
92	6	2	-27	2.319	832.9	Stable	-
90	8	2	-26	2.349	833.9	Stable	-
88	10	2	-24.5	2.365	834.6	Stable	-
90	6	4	-28.5	2.237	831.9	Unstable	-
88	8	4	-27	2.256	832.7	Stable	-
86	10	4	-25.5	2.303	833.6	Stable	-
88	6	6	-25	2.170	830.2	Stable	229
86	8	6	-23.5	2.218	831.6	Stable	-
84	10	6	-23	2.267	832.3	Unstable	245
94	6	-	-11.3	2.472	834.6	Stable	-
100	-	-	-21.8	2.391	832	Stable	605

presence of oxygenates could be presumed. Some of these properties are shown in Table 4. Density of blends increases with the content of FAME, and decreases linearly with the content of EtOH. Identical trends are observed also for viscosities of studied blends. The densities and viscosities of the blends FDO – FAME – EtOH with relatively low content of biocomponents meet the requirements of the EN 590 with the density in the range 820 to 845 kg m^{-3} at 15°C and viscosity between 2.0 and 4.5 mm^2 s^{-1} at 40°C. The presence of FAME alone in the FDO – FAME blend results in CFPP increase, however in ternary mixtures FDO – FAME – EtOH the CFPP is changed negligibly in comparison to FDO. However, the information about CFPP is misleading due to phase instability at low temperature and separation of the system into two liquid phases. The presence of two phases does not, in principle, influence the filterability at low temperature, but the CFPP value is therefore illusory. Despite poor lubricity of input FDO, the lubricity of blended fuels with EtOH and FAME is excellent also at high EtOH proportion provided the FDO – FAME – EtOH phase stability. FAME act as an efficient lubricant.

Engine performance tests

When selecting modes of testing engines, the considerations were as follows; when measured with a certain fuel, the emissions at maximum performance were set. In the next set of measurements, emissions at maximum torque were determined. In the last part of the emissions measurements, emissions at half load and maximum engine speed were stated. By these conditions, the increase production of aldehydes is expected (Henein, 1973, 1973) which is related to lowering the combustion temperature at lower loads, at higher speeds and shorter time of the combustion process. The aim of these measurements was to show that the tested materials have useful properties comparable to that of fossil fuel.

Table 5 summarizes the results of engine performance tests, acquired with prepared blended fuels with the use of the testing engine MD UR IV. As expected, the results in Table 5 show the highest value for maximum torque and maximum power output in the case of FDO, which applies for all tested regimes. Brake specific fuel consumption (BSFC) shows identical trend. This is related to lower energetic content of oxygenate and roughly corresponds to their proportion in the blend. The differences in output parameters are therefore not large and do not exceed 5%.

The same set of blended fuels was tested also with another testing engine 2.5 UI. The results are shown in Table 6. Maximum values for torque and output belong naturally also here to FDO as the fuel with the highest energy content, but the differences are even smaller than in the case of the testing engine MD UR IV. Specific consumption is lowest for FDO at all performances at given speeds. At the 2.5 UI testing engine acceleration was also evaluated, its values are shown in Table 7. The changes of

Table 5. Basic parameters of the MD UR IV engine. Regulated emissions at maximum power output, maximum torque and half load at maximum engine revolutions.

Fuel	Rev. (min^{-1})	Max.torque (N m)	Max. power (kW)	BSFC (g/kWh)	CO (vol. %)	NO_X (ppm)	CHx (FID) (ppm)	Opacity HSU (%)
A	2200	282	64.9	273.0	0.134	441.8	18	49.9
	1640	392	67.3	244.3	0.246	500.0	20	43.9
	2233	222	51.9	292.6	0.112	298.4	18	33.1
B	2210	279	64.6	274.4	0.160	445.8	17	46.0
	1600	386	64.6	249.3	0.192	601.8	16	41.4
	2223	223	45.2	289.0	0.060	313.0	14	20.9
C	2210	280	64.8	278.7	0.178	461.0	17	38.7
	1660	376	65.3	252.2	0.236	652.0	24	33.2
	2224	194	45.1	287.6	0.070	380.4	19	18.2

A – Fossil diesel oil. B – 93% FDO + 2% EtOH + 5% FAME. C – 90% FDO + 3% EtOH + 7% FAME. Water content in EtOH 0.7% w/w.

Table 6. Performance characteristics, break specific fuel consumption and opacity measured on 2.5 UI engine.

Fuel	Max. output (kW)	Max. torque (N m)	BSFC (g/kWh)			Opacity HSU (%)
			3.3 kW	7.9 kw	19.8 kW	
A	127	476	705	524	361	17
B	125	466	760	547	385	14.3
C	126	464	767	545	383	12.6

Abbreviations – see Table 5.

Table 7. Acceleration times in seconds of tested fuels measured on 2.5 UI engine.

Fuel	40→80 km/h (2nd gear)	60→100 km/h (3rd gear)	80→120 km/h (4th gear)
A	5.3	10.2	21.7
B	5.4	10.2	21.6
C	5.2	9.9	20.2

Abbreviations – see Table 5.

acceleration are minimal, oxygenate components do not impair the vehicle dynamics.

The presence of oxygenates up to 10 vol. % does not impair the fuel parameters of blends, with the exception of the flash point. Oxygenates of ester type (FAME) ensure excellent lubricity of the blend. Performance characteristics of testing engines fuelled with blends of oxygenate with FDO are not significantly different from the characteristics for the FDO itself. This finding is also consistent with observations of Torrez-Jimenéz (2011) where no significant changes were observed at ethanol content up to 15%. Slightly lower power output and higher BSFC of blended fuels are the result of lower energetic

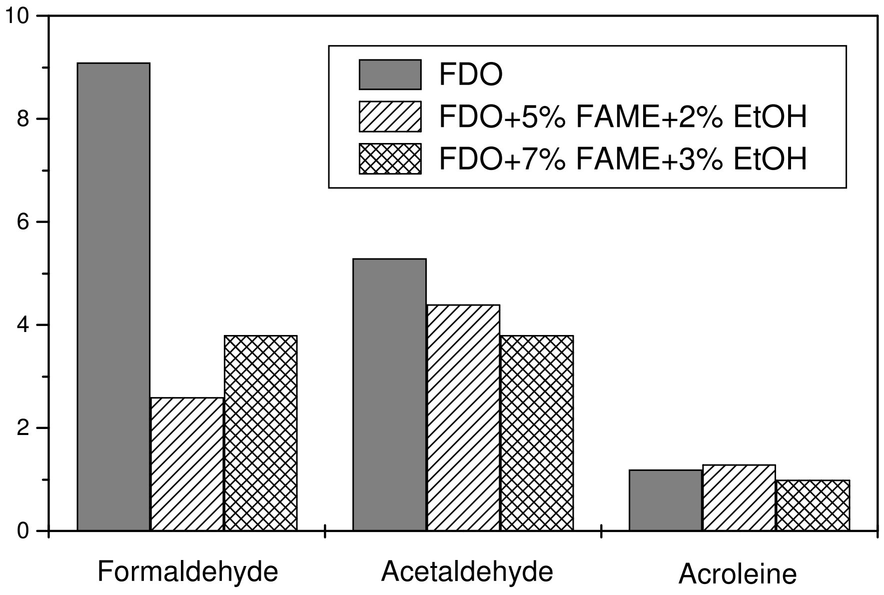

Figure 1. Concentration of formaldehyde, acetaldehyde a acroleine in µg/l in exhaust gases at maximum engine revolutions and at half load of the engine measured on MD UR IV engine. Water content in EtOH 0.7% w/w.

content of these fuels.

Emission tests

Regulated CO, NOx and HC emissions of tested blends measured during the operation of the engine MD UR IV and summarized in Table 5 depend on the engine regime. The values at the level of about one half in comparison to FDO were achieved at maximum engine revolutions and half load for both tested oxygenated fuels. For the engine with direct injection, the regime of maximum torque is strongly influenced by adjustment of fuel injection. In non-supercharged engines the addition of EtOH and FAME can lead to increase of NOx, in supercharged engines to decrease of NOx. The system is very sensitive to excess of air in fuel beam (Henein, 1973).

The opacity of oxygenated blends is lower than that of FDO, which is in accordance with published data. Marked reduction of opacity was observed at maximum engine revolutions at half load for both tested oxygenated blends. Figure 1 shows the concentration of formaldehyde, acetaldehyde and propenale (acroleine) in exhaust gases at maximum engine revolutions and half engine load. The presence of oxygenate has not marked influence on the content of aldehydes in exhaust gases in this working regime, as well as other tested regimes and the contents of non-regulated emissions are relatively low. Aldehydes are formed especially in the engine regimes with high engine revolutions and low loads and imperfect combustion of lean blends at the outer edge of the fuel beam – quenching zone with short reaction time (high engine revolutions) at low temperatures (low engine load) (Henein, 1973). At the same volume of fuel batch, different chemical composition of the fuel is reflected in the change of the theoretical air consumption. Diesel engine then works with increased excess of air in comparison to FDO, because the alternative oxygen-containing fuels deplete the blend. In case of EtOH the vapor pressure of the fuel increases, this influences the volume of quenching zone, i.e. the zone of aldehyde formation (Henein, 1973). By shortening the ignition delay, the thickness of quenching zone decreases, which decreases the cetane number of the fuel.

Emissions measured during the tests of studied blends with the engine 2.5 UI are shown in Table 8 at steady-state regime during idle running at the constant speeds of 60, 90 or 120 km/h. The CO emissions are at zero level for all fuels at all speed regimes including idling. Zero content of CO in the emissions is associated with the supercharged engine used in the tests. With a high excess of air, the fuel has a chance to completely burn out. The blends of fuels with oxygenate component have usually lower HC emissions, similar tendency is observed for NOx. The comparison of the emission levels from both tested engines is problematic due to different conditions of measurement and also a different conception of the engines. However, the trends are maintained, the blended fuels exhibit comparable emission characteristics for both testing engines. Blended fuels with the content of oxygenate biocomponent exhibit markedly lower opacity in comparison to FDO. Non-regulated emissions (aldehydes) vary at the level of tenths to units of µg/l

Table 8. CO, HC and NOx emissions of tested fuels measured on 2.5 UI engine.

		A	B	C
CO (vol. %)	Idle	0	0	0
	60 km/h (3.3 kW)	0	0	0
	90 km/h (7.9 kW)	0	0	0
	120 km/h (19.8 kW)	0	0	0
HC (ppm)	Idle	0	0.4	1.6
	60 km/h (3.3 kW)	19.6	15.8	13.8
	90 km/h (7.9 kW)	31	25.2	25.8
	120 km/h (19.8 kW)	20	20.4	19.6
NOx (ppm)	Idle	44	33	9.4
	60 km/h (3.3 kW)	87.6	80.8	83.6
	90 km/h (7.9 kW)	294.6	277.6	288
	120 km/h (19.8 kW)	476.2	459.2	462.6

Abbreviations – see Table 5.

without significant influence of the engine regime.

It is difficult to explain the impact parameter changes of the fuel and engine regime on the unregulated emissions, because the mechanism of their formation and conditions in the combustion chambers are not well known (Meyer, 2010).

Conclusions

The performed study showed that EtOH is an efficient oxygenate of diesel fuel blends decreasing the PM in emissions. Low temperature phase stability of two-component blended fuels FDO – EtOH down to -10°C, is strongly dependent on the water content in the blend. FDO and EtOH form phase stable systems at temperatures down to -10°C at the portion of 4% w/w of dry EtOH with water content up to 0.20% w/w. The water content above 0.70% w/w in EtOH does not guarantee the system stability. Alkylamides-based additive (emulgator) at the content up to 1% w/w increases the low-temperature stability and acts as an anticorrosive agent. In ternary blends FDO – FAME – EtOH, the FAME act as a co-solvent and increase the solubility of EtOH in FDO, also at increased water content in the blend. EtOH with 0.70% w/w of water at the 4% w/w portion forms a stable system with FDO at -10°C, if the portion of FAME is at least twice the amount of EtOH. The presence of oxygenates does not impair the fuel parameters of blends, with the exception of the flash point. The presence of oxygenates of ester type (FAME) ensures excellent lubricity of the blend. Performance characteristics of testing engines with oxygenate – FDO blends are not significantly different from the characteristics for the FDO itself. Slightly lower power output and higher BSFC of blended fuels are the result of lower energetic content of these fuels. Opacity of blended fuels is significantly lower in comparison to standard FDO. Regulated emissions (CO, HC, and NOx) depend on the engine regime. Non-regulated emissions, especially aldehydes are at low level, positive influence of oxygenates on these emissions is visible at higher engine loads.

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