THE EFFECT OF RAPESEED OIL BLENDING WITH ETHANOL ON ENGINE PERFORMANCE AND EXHAUST EMISSIONS

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Abstract

The article presents the bench testing results of a four stroke, four cylinder, direct injection, unmodified, naturally aspirated diesel engine operating on neat rapeseed oil (RO) and its 2.5vol% (ERO2.5) and 7.5vol% (ERO7.5) blends with ethanol. The purpose of the research was to investigate the effect of ethanol inclusion in the RO and preheating temperature on bio-fuel viscosity, engine brake power, specific fuel consumption, break thermal efficiency and emission composition changes, especially NO, NO_2, NO_x, CO, CO_2, HC and smoke opacity of the exhausts.

Inclusion in the RO 2.5 and 7.5vol% of ethanol the blend viscosity at ambient temperature of 20 ^oC diminishes by 9.2 and 28.3%. During operation under constant air-to-fuel equivalence ratio λ = 1.6, blends ERO2.5 and ERO7.5 ensure the brake mean effective pressure (bmep) lower at the maximum torque 1800 min^{-1} by 0.5 and 2.3% (bmep=0.770 MPa) and at rated 2200 min^{-1} speed by 2.4 and 9.1% (bmep=0.740 MPa), correspondingly, than that of neat RO case. The bsfc at maximum torque (248.7 g/kWh) and rated power (247.5 g/kWh) for blends ERO2.5 and ERO7.5 is higher by 1.3-4.4% and 4.2-10.7% and the brake thermal efficiency lower by 0.5-1.5% and 3.3-7.6%, respectively. The tests revealed that during operation of the fully loaded engine at rated 2200 min^{-1} speed, ethanol inclusion in the RO up to 7.5vol% diminishes NO, NO_x, HC, CO_2 emissions, smoke opacity and temperature of the exhausts however it may increase simultaneously NO_2, NO_2/NO_x and CO emissions.

Keywords: *diesel engine, rapeseed oil, ethanol, effective parameters, emissions, smoke opacity*

1. Introduction

In relation with eventual depletion of mineral fuels and high market prices, the biggest concern of 21st century is linked with increased carbon dioxide emissions, ambient air pollution and environmental degradation that all together lead to climate changes created by growing "green-house" effect and global warming. The Commission White Paper European policy predicts that by year 2010, the CO_2 emissions from transport will have risen to about 1113 billion tons annually with the main responsibility resting on road transport, which amounts for 84% of the transport related CO_2 emissions [5]. It is expected that at the 2030 horizon the number of road vehicles in the OECD countries will be the same as in the rest of the world, which means doubling the today's worldwide vehicle number.

Directive 2003/30EC of the European Parliament and Council calls for Member States to ensure a minimum proportion of bio-fuels and other renewable fuels for transport purposes on their markets by the end of 2010 shall be 5.75% on the basis of energy content. To achieve this goal, along with popular in Europe Rapeseed Methyl Ester (RME), neat rapeseed oil (RO) could also be used for the local engine fuelling. Potential advantages and disadvantages of the RO as bio-fuels variety extender have been elucidated in investigation [6]. RO is also sulphur free (0.04-0.002%), during short term application suggests a bit higher maximum brake thermal efficiency (bte = 0.38-0.39) than that of the diesel fuel (0.37-0.38), by 40.5% to 52.9% lower CO, 27.1% to 34.6% lower smoke opacity and close to zero (2-3 ppm) HC emissions [7].

This environmental friendly and renewable fuel is less depended on the fiscal policy and more economically attractive especially when applied along with pressing of oilcake for farming. Bearing in mind that inexpensive low energy cold-pressing (<50 ^oC), filtering, sedimentation and decanting facilities could be established in some rural enterprises, usage of neat RO for the local engine fuelling suggests real advantages related to minimised production and transportation prices and its competitiveness on the market could be even better comparing with RME. According to the latest prognoses on the utilisation trends of bio-fuels [1], production of pure bio-diesel is on the order of 120-175% more expensive than conventional fuels and not profitable without fiscal support.

However, the biggest concern related to direct use of neat RO as bio-fuels variety extender associates with its high viscosity that at ambient temperature of 20 ^oC is about 13 times higher comparing with diesel fuel. High viscosity of the RO may aggravate oil flow in the fuel lines worsening performance of the injection pump and permeability of fuel sprays, its low volatility and high both flash point (220-280 ^oC) [2] and auto-ignition temperature (320 ^oC) [9] may affect fuel evaporation and combustion of premixed portions, engine performance and related emissions. Besides, using of neat RO for a longer time may provoke reliability problems linked with injector nozzle cocking, engine inner parts coating, fuel filter plugging and sump oil ageing.

One of the methods allowing to reduce oil's viscosity is its mixing with a lighter ethanol that is also renewable and environmental friendly, safe to store and easy to handle, not toxic and sulphur free material, and when applied in proper proportions, ethanol can increase the energy conversion efficiency, improve fuel economy, solve the fuel shortage problems and reduce harmful emissions of the exhausts [11]. Ethanol differs as having 19.5 times lower molecular weight and its viscosity at temperature of 40 ^oC is 27 times lower than that of RO, which along with low pour point at the temperature below of –40 ^oC may improve blend's flow through delivery lines, injection and atomisation quality and increase fuel sprays penetration in the combustion chamber volume.

2. Purpose of the research

The purpose of the research is to investigate the effect of rapeseed oil blending with ethanol and preheating temperature on its viscosity and conduct comprehensive bench tests to study the brake mean effective pressure, brake specific energy consumption, emission composition changes, such as nitrogen oxides NO, NO_2, NO_x, carbon monoxide CO, dioxide CO_2, total unburned hydrocarbons HC and smoke opacity of the exhausts when fuelling the engine alternately with neat rapeseed oil and its 2.5 and 7.5vol% blend with ethanol over a wide range of loads and speeds.

3. Objects, apparatus and methods of the research

Tests have been conducted on four stroke, four cylinder 59 kW DI diesel engine D-243 with splash volume 4.75 dm^3, cylinder bore 110 mm, piston stroke 125 mm and compression ratio 16:1. In order to increase flow rate of viscous RO the fuelling system was modified by mean of installing of two joined in parallel a honeycomb shaped design fine porous fuel filters. The fuel was delivered by an in line fuel injection pump thorough five holes injection nozzles into a toroidal type combustion chamber in a piston head with the initial fuel injection starting at 25^o before top dead centre. The needle valve lifting pressure for all injectors was set to 17.5±0.5 MPa.

Load characteristics of the engine were taken at the revolution frequencies 1400, 1600, 1800, 2000 and 2200 min^{-1} when running it alternately on the neat RO and its 2.5 (EREO2.5) and 7.5vol% (ERO7.5) blends with ethanol. Torque of the engine was measured with 110 kW electrical AC stand dynamometer and the revolution frequency of the crankshaft was determined with the universal ferrite-dynamic stand tachometer TSFU-1. The fuel mass consumption was measured by weighting it on the electronic scale SK-1000 and the volumetric air consumption was determined by means of the rotor type gas counter RG-400-1-1.5 installed at the air tank for reducing pressure pulsations.

From respective measurements the brake specific energy consumptions (bsec) expressed in J/kWh and air-to-fuel equivalence ratios λ, representing typical engine loading conditions, for the neat RO and various ERO blends were computed, where all operational factors such as the air and fuel flow rate, their densities, calorific values of bio-fuel components, their blending ratio and fuel bound oxygen all were taken into account.

The amounts of carbon monoxide CO (ppm), dioxide CO_2 (vol%), nitric oxide NO (ppm), nitrogen dioxide NO_2 (ppm) and the residual content of oxygen O_2 (vol%) in the exhausts were measured with the Testo 33 gas analyser. The total emission of nitrogen oxides NO_x was determined as a sum of both NO and NO_2 components.

The amounts of unburned hydrocarbons HC (ppm vol) and the residual oxygen O_2 (vol%), which were determined afterwards, as well as the carbon monoxide CO (vol%) and dioxide CO_2 (vol%) emissions, in the exhaust gases were additionally checked with the TECHNOTEST Infrared Multigas TANK gas analyser model 488 OIML.

The smoke opacity D (%) of the exhausts was measured with the Bosch device RTT 100/RTT 110, the readings of which are provided as Hartridge units in scale I - 100% with ±0.1% accuracy.

On the basis of test results obtained during operation of the engine on ERO2.5 and ERO7.5 blends, the differences in the brake specific energy consumption, smoke opacity and exhaust emissions generated under constant air-to-fuel equivalence ratios and, hence, the same combustion conditions for light ($\lambda = 6.0$), media ($\lambda = 3.0$) and heavy ($\lambda = 1.6$) loads from the baseline operation on neat rapeseed oil, were determined and compared.

4. The research results and discussions

It was determined that inclusion in the RO 2.5 and 7.5vol% of ethanol the oil's viscosity at ambient temperature of 20 ^{o}C diminishes correspondingly by 9.2 and 28.3% and makes much easy oil flow through the fuelling system. In order to improve further the filtration properties of RO and its blends with ethanol the bio-fuel preheating in the heat exchanger can be used as supplementary measure. Test results indicate that heating from ambient conditions of 20 ^{o}C up to the temperature of 60 ^{o}C the viscosity of neat RO and blends ERO2.5-7.5 diminishes 4.2 and 3.9-3.8 times, respectively, that improves technical properties of biofuels.

Since the comparison of engine performance is made at the same air-to-fuel equivalence ratios and speeds, it is to be noted, that the combustion conditions for all bio-fuels remain similar suggesting validate differences in changes of the brake mean effective pressure (bmep), brake specific energy consumption (bsec) and related emissions. Analysing test results one should bear also in mind that blends ERO2.5 and ERO7.5 contain correspondingly 11.4 and 12.6% of the fuel bound oxygen against 10.8% conserved in the neat RO. Taking into account that the stoichiometric air-to-fuel equivalence ratio for ethanol is much lower (9.07) than that for neat RO (12.63%), this is translated into slightly lower 12.54 and 12.36 the stoichiometric air-to-fuel equivalence ratios of blends that may also contribute to higher quantity of mixture premixed for rapid combustion.

It is observed that during operation at low 1400 min^{-1} revolutions, the bsec of blends ERO2.5 and ERO7.5 relative to neat RO case is by 4.1% lower and by 15.9% higher, respectively, for light, $\lambda = 6.0$, and approximately the same for medium, $\lambda = 3.0$, and heavy, $\lambda = 1.6$, loads (Fig. 1). Differences in the bsec between neat RO and blend ERO7.5 have tendency to diminish with speed, so that the bsec values at light and media loads coincide actually when revolutions increase up to 2000 min^{-1} and beyond. In contrast to that case, blend ERO2.5 suggests advantages that at rated 2200 min^{-1} speed convert into the bsec being lower correspondingly by 7.5% and 6.8% for both light and media loads. After transition to the heavy loads, the bsec for all bio-fuels remains nearly the same until revolution frequency increases up to 2000 min^{-1} and beyond where the situation is changed a little and the bsec of blends ERO2.5 and ERO7.5 at rated 2200 min^{-1} speed becomes higher against that of the neat RO by 3.4 and 8.3%, respectively, with the increment rate being higher the higher the percentage of the ethanol in the blend.

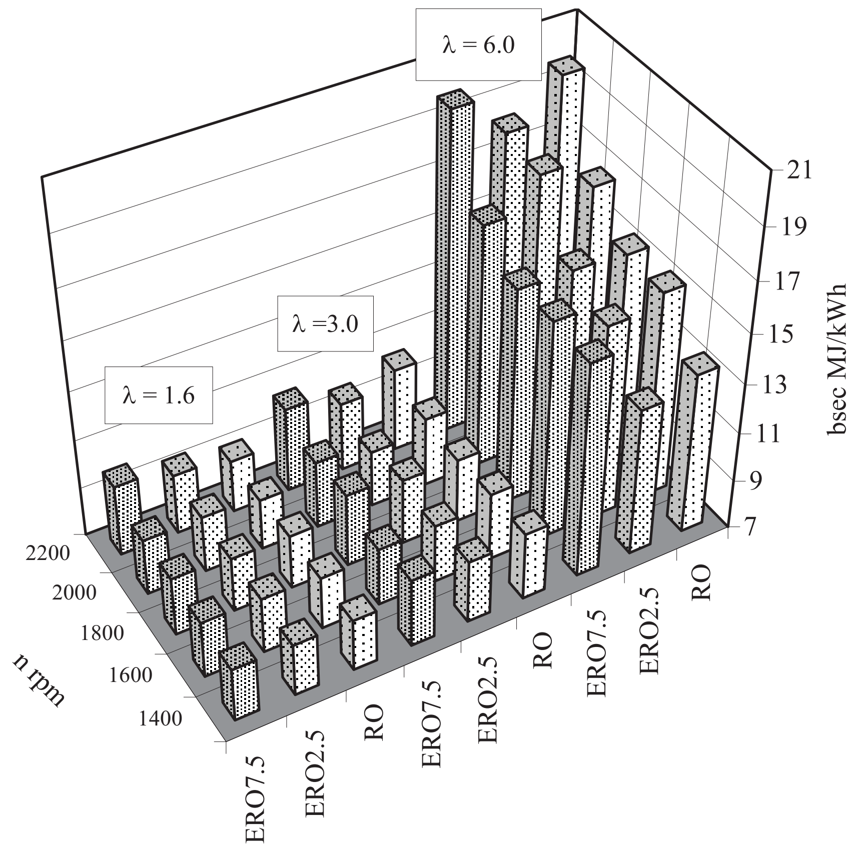

Fig. 1. Dependencies of the brake specific energy consumptions (bsec) for three biofuel origins and three typical loading groups presented by various air-to-fuel equivalence ratios λ as a function of engine speed (n)

Test results indicate that during operation under constant air-to-fuel equivalence ratio λ = 1.6 at the maximum torque 1800 min^{-1} and rated 2200 min^{-1}speed the fully loaded engine run on blends ERO2.5-7.5 develops by the same, 1.738-1.742 MJ/kg, energy content accumulated in fuel-rich mixture the bmep lower correspondingly by 0.5-2.3% and 2.4-9.1% than that of neat RO. The lower energy conversion efficiency obtained from the easy loaded engine run on oxygenated blend ERO7.5 can be obtained because of low cetane number (8) of ethanol and unstable performance of the engine due to misfiring cycles whereas the higher fuel energy consumption of the fully loaded engine at rated speed can be attributed to low calorific value (26.82 MJ/kg) of ethanol, its high both auto-ignition temperature of about 420 ^{o}C and latent heat of evaporation 910 MJ/kg that may create significant cooling effect of the fuel sprays and lead to longer auto-ignition delay, retarded start of combustion and relocate all the phases of the heat release towards the expansion stroke [8].

The emissions of NO_x along with engine performance conditions and its adjustment factors [8], depend actually on the feedstock, composition and chemical structure of the fatty acids [2] and the fuel injection timing advance determined in the case of using the rotor type Stanadyne fuel injection pump by its physical properties largely [10]. Because RO differs as having higher start of vaporisation (299 ^{o}C) related to the diesel fuel (177.8 ^{o}C) and about same vaporisation end (345-346 ^{o}C) [2], mixing RO with lighter ethanol may advance the start of vaporisation that along with the lower cetane number of ethanol and presence of fuel bound oxygen may lead to higher the NO_x emissions due to longer auto-ignition delay and higher amount of fuel premixed for rapid combustion.

Overview of experimental data revealed, that the NO and NO_x emissions reach their maximum values at the air-to-fuel equivalence ratios λ = 2.2-1.8 that corresponds approximately to 75% of engine rated power therefore the analysis of nitrogen oxides behaviour was performed for respective loading conditions. Graphs in Fig. 2 shows that during operation at low 1400 min^{-1} speed, the maximum NO emissions emerging from blend ERO2.5 are by 15.3% lower and those from ERO7.5 by 8.0% higher comparing with neat RO case. The higher NO emissions generated by blend ERO7.5 at low speed can be attributed reasonably to higher both the content of fuel conserved oxygen and portion of fuel premixed for rapid combustion during longer in units of time auto-ignition delay.

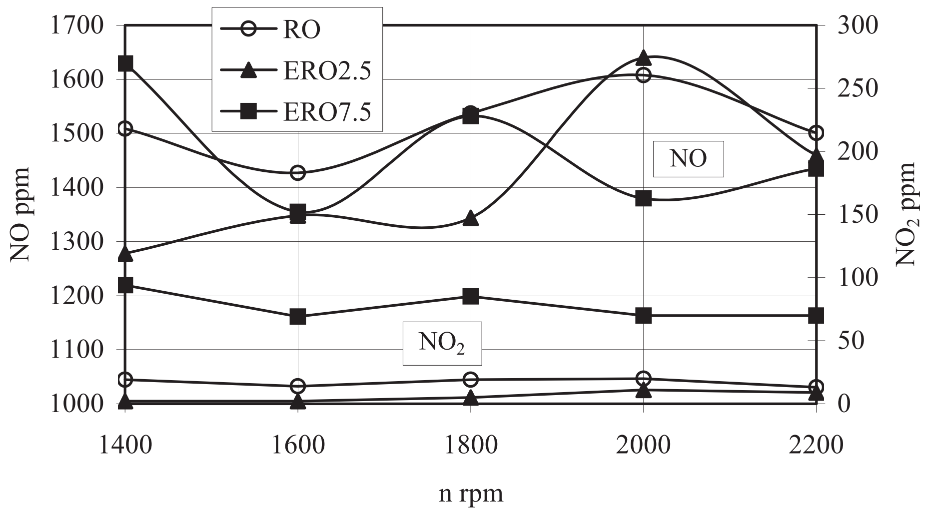

Fig. 2. The nitric monoxide NO and nitrogen dioxide NO_2 emissions emanating from neat RO and various ERO blends as a function of engine speed (n)

In spite of a high level at start, the maximum NO emissions from blend ERO7.5 fluctuate along speed axis showing clear reduction tendencies and differ actually from NO emissions generated by blend ERO2.5, which increase gradually with revolutions reaching the top 1640 ppm value at 2000 min^{-1} speed. Temperature related NO emissions behaviour correlates pretty well with changes in the energy conversion efficiency (Fig. 1) of the fully loaded engine run on considered biofuels. Because combustion process deteriorates, the maximum NO emissions from both ERO2.5 and ERO7.5 blends are lower by 2.8 and 4.4% at rated 2200 min^{-1} speed than that of neat RO.

The higher by 3.5-5.4 times NO_2 emissions (69-94 ppm) emanating throughout the hole speed range from blend ERO7.5 relative to neat RO case (13-20 ppm) also indicate that combustion process of plenty oxygenated biofuels is complicated enough and proceeds, likely, with presence of cooler regions, which are widespread across the combustion chamber and may quench the conversion back to NO [4]. Combustion of heterogeneous mixture within close to stoichiometric zones can be even more aggravated due to poor miscibility of ethanol with RO, especially at blending ratios higher than 9vol% [11]. For verification of such point of view there underneath of Fig. 2 one can see the NO_2 emissions from low concentration blend ERO2.5 that start from close to zero, 2 ppm, level and extend over the speed axis up to 11 ppm only, suggesting from 9.5 to 1.4 times lower NO_2 emissions relative to neat RO.

The maximum of the total NO_x emissions as a sum of both nitric monoxides NO and nitrogen dioxides NO_2 accompanied by NO_2/NO_x ratios determined for neat RO, ERO2.5 and ERO7.5 blends as a function of speed have been superimposed in Fig. 3. Analysis of graphs shows, that within the lower speed 1400-1800 min^{-1} range the maximum NO_x emissions emanating from blend ERO7.5 are up to 12.8-3.9% higher and those from blend ERO2.5 by 16.4-13.3% lower relative to neat RO case. The higher NO_x emissions from blend ERO7.5 have been obtained because of both by up to 8.0% higher nitric monoxide NO and by 4.5 to 4.9 times higher nitrogen oxide NO_2 emissions that can be attributed respectively to more intensified burning of mixture premixed and presence within the combustion chamber volume of cooler regions. Because of different NO and NO_2 emissions behaviour with speed, the total NO_x emissions emerging from ERO2.5 and ERO7.5 blends show convergence tendencies and at rated 2200 min^{-1} speed are lower by 3 and 0.6%, respectively.

According to the latest test results of the International T 444E HT turbocharged and intercooled 7.3 L CI engine fuelled with 5% and 10% ethanol-diesel fuel blends, there decrease in NO_x emissions also was measured by close to 3% and authors came to the conclusion that ethanol could act as an effective NO_x emissions reducing additive [3]. The other bio-diesel tests conducted on the International V-8 diesel fuelled with 100% soy methyl ester, 2% bio-diesel, 10% ethanol-diesel fuel, and 5% ethanol in bio-diesel also showed that there no correlation exists between fuel conserved oxygen and the total NO_x emissions [12]. Thus in the case of RO blended with ethanol, the NO_x emissions behaviour differs actually from bio-diesel test results reported in Ref. [2,7].

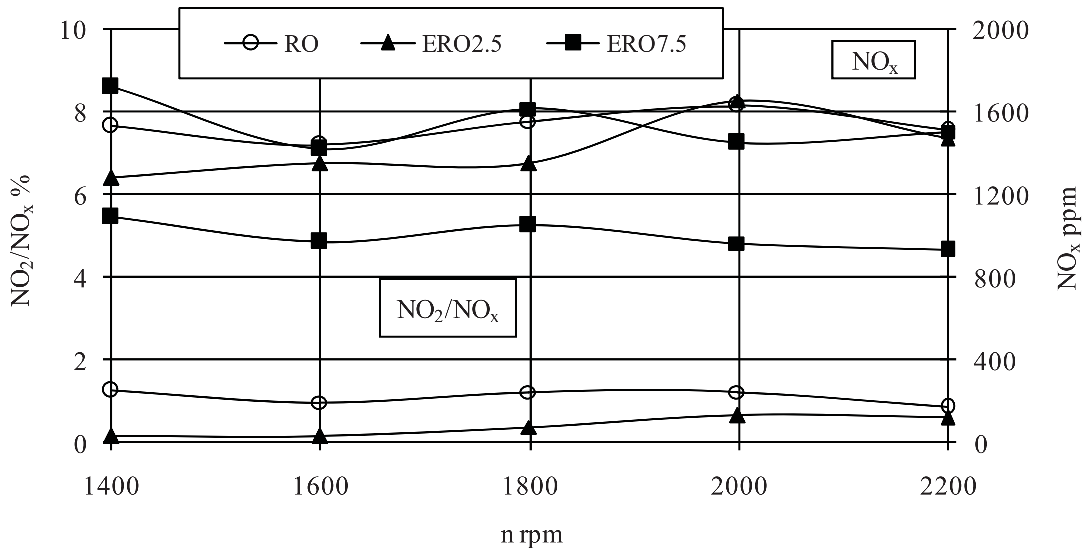

Fig. 3. The maximum of the total NO_x emissions and NO_2/NO_x ratios emanating from neat RO and various ERO blends as a function of engine speed (n)

Because the NO_2/NO_x ratios may carry important information about combustion peculiarities of oxygenated blends special interest should be focused on changes of the NO_2/NO_x emissions with speed. As one can observe in Fig. 3, the NO_2/NO_x ratios generated by blend ERO7.5 fluctuate along speed axis at approximately 5% level, i.e. extend over the emissions from neat RO as much as 3.9 to 5.4 times and do not undergo significant changes with revolutions. In contrast to that case, the NO_2/NO_x ratios determined from blend ERO2.5 suspend at considerably lower, 0.15-0.67%, levels remaining from 8.0 to 1.4 times below the base-line parameters.

Emissions of CO vary with the engine load, speed and quantity of ethanol premixed into RO. Starting at light load and low 1400 min^{-1} speed from comparably high 332 ppm (RO) and 971-473 ppm (ERO2.5-7.5) levels, CO emissions diminish slightly for medium loads and after transition to rated speed increase again correspondingly up to 596 ppm and 571-770 ppm for heavy loading conditions, $\lambda = 1.6$, (Fig. 4). When fuelling of the fully loaded engine with blend ERO2.5, CO emissions throughout the whole speed range are slightly lower whereas those from blend ERO7.5 are lower by 9.3% at low 1400 min^{-1} revolutions and higher by up to 29.2% at rated 2200 min^{-1} speed. The lower CO emissions from blends ERO can be attributed to the oxygenated nature (34.8%) of ethanol whereas their gradual increase with speed when using blend ERO7.5 correlates pretty well with lower both energy conversion efficiency (Fig. 1), NO emissions and higher levels of NO_2 (Fig. 2) accompanied by higher NO_2/NO_x ratios (Fig. 3).

The smoke opacity increases with load and fuel portion injected from about zero level reaching at 1400 min^{-1} speed maximum 39.3% (ERO2.5), 55.5% (ERO7.5) and 72.0% (RO). As soon as rotation speed increases, the visible smoke from the fully loaded engine diminishes due to higher injection pressure, better atomization of viscous RO droplets and intensified mixing of the fuel by cylinder air swirl. Because of higher oxygen content, smoke opacity from blends ERO during operation at full throttle and low 1400 min^{-1} revolutions is by 45.4 and 22.9% lower and for rated 2200 min^{-1} speed do not exceeds 22.7-22.0% that correlates well with other related emissions.

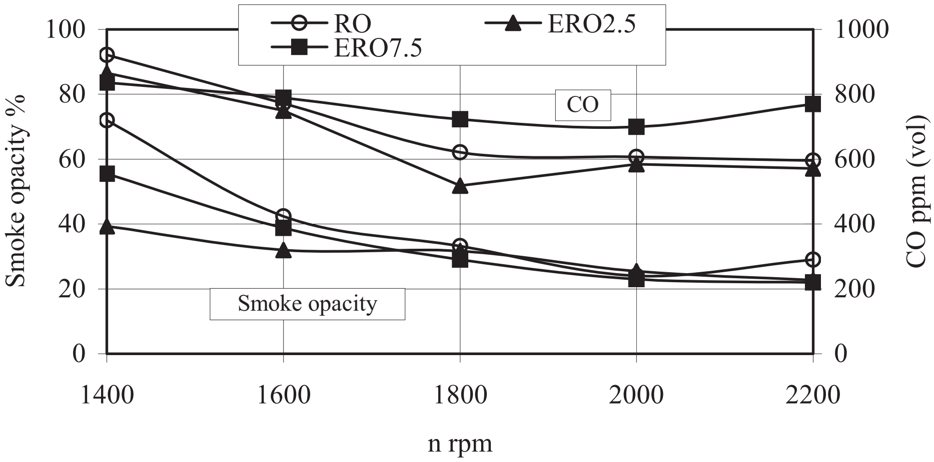

Fig. 4. Dependencies of CO emissions and smoke opacity of the exhausts from neat RO and various ERO blends as a function of engine speed (n)

Emissions of unburned hydrocarbons HC from blends ERO2.5-7.5 are also lower by 5.8-14 ppm and residual oxygen content in the exhaust manifold is higher 11.3-14.2vol% comparing with that of neat RO 10.6vol%, the CO_2 emissions and temperature of the exhausts from the fully loaded engine, $\lambda = 1.6$, diminish with the ethanol inclusion in the RO from 7.0 to 6.3vol% and 490 to 460 ^{o}C, respectively, because of lower both C/H ratio and calorific value of ethanol.

Test results indicate that the ethanol bond oxygen effectively contributes diminishing the maximum NO, NO_x emissions and visible smoke emerging from the fully loaded engine run on ERO blends but it comes into effect to late in the cycle and, probably, of little help to cope with the whole situation aggravated by the presence of heavy RO molecules to insure high energy conversion efficiency under heavy loading conditions and suggest lower NO_2 and CO emissions therefore new evidence concerning combustion peculiarities of RO and ethanol blends must await further investigations.

5. Conclusions

1. During operation of the diesel engine D-243 under constant air-to-fuel ratio, $\lambda = 1.6$, at the maximum torque 1800 min^{-1} mode and rated 2200 min^{-1} speed, blends ERO2.5-7.5 ensure the power output lower by 0.5-2.3% and 2.4-9.1%, respectively, relative to that of neat RO case. The brake specific energy consumption (bsec) in MJ/kWh of blends ERO2.5 and ERO7.5 at 1400 min^{-1} speed is lower by 4.1% and higher by 15.9%, correspondingly, for light and approximately the same for medium and heavy loading conditions whereas during operation at rated 2200 min^{-1} speed with the fully opened throttle, the bsec increases against that of neat RO by 3.4 and 8.3%, respectively.
2. The maximum NO, NO_2 and NO_x emissions from blend ERO7.5 at low 1400 min^{-1} speed are correspondingly by 8.0%, 4.9 times and by 12.8% higher. The total NO_x emissions from blends ERO2.5 and ERO7.5 at rated 2200 min^{-1} speed are lower by 3% and 0.6% due to lower, probably, energy conversion efficiency related cylinder gas temperature. The higher NO_2 emissions within the whole speed range indicate that combustion process of blend ERO7.5 proceeds, likely, with the presence of cooler regions, which may quench the conversion back to NO.
3. Emissions of CO from the fully loaded engine run on blends ERO2.5 and ERO7.5 at rated 2200 min^{-1} speed are by 4.2% lower and by 29.2% higher, respectively, relative to neat RO case

whereas the smoke opacity at 1400 and 2200 min^{-1} speeds is correspondingly by 45.4-22.9% and 21.7-24.1% lower and during operation at the rated power do not exceeds 22.7-22.0%. Emissions of HC from blends ERO2.5-7.5 are also lower by 5.8-14 ppm along with lower both the CO_2 emissions from 7.0 to 6.3vol% and temperature of the exhausts from 490 to 460 ^oC.

The test results indicate that due to lower cost and environmental friendly emissions, up to 2.5vol% rapeseed oil and ethanol blends ERO2.5 could be regarded as potential candidates to be used for the local engine fuelling. The broad-scale using of ERO blends in unmodified diesel engines should be dependent on all benefits and detriments revealed during practical exploitation.

References

[1] Demirbas, M. F., Balat, M., *Recent advances on the production and utilization trends of bio-diesel: A global perspective,* Energy Conversion and Management, Vol. 47, Issue 15-16, p. 2371-2381, 2006.

[2] Graboski, M. S., McCormick, R. L., *Combustion of Fat and Vegetable Oil Derived Fuels in Diesel Engines*, Progress in Energy and Combustion. Scientific. Vol. 24 p. 125-164, Elsevier Science Ltd, 1998.

[3] Hansen, A. C., Gratton M. R., Yuan, W., *Diesel engine performance and NO_x emissions from oxygenated biofuels and blends with Diesel fuel*. Transactions of the ASABE, Vol. 49(3) p. 589-595, 2006.

[4] Heywood, J. B., *Internal Combustion Engine Fundamentals*, Co - Singapore for manufacture and export (International edition) 930 p.1988.

[5] Labeckas, G., Slavinskas, S., *The effect of rapeseed oil methyl ester on direct injection Diesel engine performance and exhaust emissions,* Energy Conversion and Management, Vol. 47, Issues 13-14, p. 1954-1967, 2006.

[6] Labeckas, G., Slavinskas, S., *Performance of direct-injection off-road Diesel engine on rapeseed oil*. Renewable Energy, Vol. 31, Nr. 6, p. 849-863, 2006.

[7] Labeckas, G., Slavinskas, S., *Performance and exhaust emissions of direct-injection Diesel engine operating on rapeseed oil and its blends with Diesel fuel,* TRANSPORT: Journal of Vilnius Gediminas Technical University and Lithuanian Academy of Sciences, Vol. 20, nr. 5, p. 186-194, 2005.

[8] Lotko, W, Lukanin, V. N., Khatchiyan, A. S., *Usage of Alternative Fuels in Internal Combustion Engines*, Moscow: MADI, 311 p. (in Russian), 2000.

[9] Saveljev, G., *Alternative fuels in agricultural sector*, Alternative fuel, nr 1 (25), p. 64-70 (in Russian), 2006.

[10] [10] Tat, M. E., Gerpen, J. H. V., *Fuel Property Effects on Injection Timing, Ignition Timing and Oxides of Nitrogen Emissions from Biodiesel-Fueled Engines*, Paper Number: 046081. An ASAE Annual International Meeting Presentation, Ottawa, Ontario, Canada, 1-4 August, 2004.

[11] Yasufumi, Yoshimoto, Masayuki, Onodera, *Performance of a Diesel Engine Fuelled by Rapeseed oil Blended with Oxygenated Organic Compounds*, SAE Technical Paper Series 2002-01-2854, p. 9. 2002.

[12] Yuan, W., Gratten, M. R., Hansen, A. C.,. *Parametric Investigation of NO_x Emissions from Biofuels for Compression-Ignition Engines*, An ASAE Annual International Meeting Presentation, Tampa, Florida, USA, p. 21, 17-20 July 2005.