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ANALYSIS OF PERFORMANCE AND EMISSIONS OF THE EXHAUSTS OF OFF-ROAD DIESEL ENGINE OPERATING ON THREE AGENT ETHANOL, PETROL AND RAPESEED OIL BLEND

TRIJŲ KOMPONENTŲ ETANOLIO, BENZINO IR RAPSŲ ALIEJAUS MIŠINIU VEIKIANČIO TRAKTORINIO DYZELINIO VARIKLIO DARBO RODIKLIŲ IR DEGINIŲ EMISIJOS ANALIZĖ

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The article presents comparative analysis of bench testing results of a four stroke, four cylinder, direct injection, unmodified, naturally aspirated diesel engine operating on rapeseed oil (RO) and its 7.5vol% blend with ethanol (E) and petrol (P) premixed in equal 50vol% (E) and 50vol% (P) proportions (EPRO7.5). The purpose of the research is to investigate the simultaneous effect of both agents on brake mean effective pressure (bmep), brake specific fuel consumption (bsfc), brake specific energy consumption (bsec), the brake thermal efficiency (bte) and emission composition changes, including NO, NO_2, NO_x, CO, CO_2, HC and smoke opacity of the exhausts.

The bmep of the fully loaded, λ = 1.6, engine operating at the maximum torque 1800 min^{-1} mode and rated speed of 2200 min^{-1} on blend EPRO7.5 is higher by 1.0% and lower by 0.8%, respectively, comparing with that of RO (0.770 and 0.740 MPa). Brake specific fuel consumption changes against that of RO from by 1.1% higher level for easy load to lower by 3.7% for heavy load at 2200 min^{-1} speed. The brake specific energy consumption of the loaded engine from by 9.5% and 5.0% higher levels for low 1400 and 1600 min^{-1} speeds diminishes against that of RO by 3.3%, 5.8% and 4.3% for 1800, 2000 and 2200 min^{-1} speeds. The composite blend ensures maximum brake thermal efficiency 0.41-0.42 against that of RO (0.39) at 2000 and 2200 min^{-1} speed.

Maximum NO_x emission emanating from three agent blend EPRO7.5 is from 27.7% (1951 ppm) to 2.1% (1546 ppm) higher comparing with that, 1528 ppm and 1514 ppm, from pure RO at 1400-2200 min^{-1} speeds. Both carbon monoxide CO emission and smoke opacity from the fully loaded engine operating on blend EPRO7.5 are lower by 28.6% (658 ppm) and 67.5% (23.4%) at low 1400 min^{-1} speed whereas for the rated 2200 min^{-1} speed, CO emission increases by 16.1% (692 ppm) and smoke opacity diminishes by 17.6% (23.9%) relative to corresponding data measured from RO.

The emission of HC is higher by 9-12 ppm, CO_2 produced from blend EPRO7.5 amounts 7.9vol% and temperature of the exhaust remains nearly the same 510^{o}C as that from RO at rated 2200 min^{-1} performance mode.

Diesel engine, rapeseed oil, ethanol, petrol, effective parameters, exhaust emissions, smoke opacity

Introduction

The Directive 2003/30EC of the European Parliament and Council calls for Member States to promote biofuels using in transportation and agricultural sectors to preserve fossil fuel resources, diminish air pollution, protect environment and peoples' health too. Popular in Europe rapeseed oil (RO) could be used for local tractor powering to alleviate fuel shortage problems and diminish air pollution due to closed-cycle CO_2 circulation. Potential advantages and disadvantages of using rapeseed oil for compression ignition engine fuelling have been discussed by many researchers [1-4]. The analysis of the testing results, shows that reasonably higher rapeseed oil consumption (248-255 g/kWh) in comparison with the diesel fuel (221-226 g/kWh) can be attributed to its lower net heating value because the maximum brake thermal efficiency (0.37-0.38) for RO is a bit higher (0.38-0.39) [5]. Heating of rapeseed oil to temperature of 60^{o}C proved itself as effective measure for reducing oil viscosity, improving its flow through fuelling system and reducing the brake specific energy consumption under light bmep = 0.15 and 0.20 MPa loads by 11.7-7.4%, respectively. The main inconvenience that obstructs using of pure RO for tractors fuelling is related to its high density and viscosity that aggravates oil flow through fuelling system.

Mixing of oil with a lighter diesel fuel reduces viscosity, improves calorific value and lubricating properties of the blend and compensates effect of diminished sulphur content in diesel fuel, which has been lowered in recent years from 2000 ppm to 200-500 ppm and even to 1 ppm for some city buses [6]. The other effective method allowing to reduce of oil viscosity and to enhance fuel oxygen content in the biofuel blend is mixing of RO with alcohols. According to the investigation [7], alcohols and alcohol-esters allow obtain of completely dissolved RO mixtures with the inclusion rate up to 29% and 33%, however ethanol mixes with RO properly up to 9% only. Bigger amounts of ethanol due to ethanol water included may lead to the phase separation in the blend.

The addition of ethanol in the RO has actually two contradictory effects on biofuel blends (ERO) properties. On one part, ethanol is known as having 19.5 times lower molecular mass and its viscosity is 27 times lower at temperature of 40^{o}C comparing with that of RO, which together with a low pour point of -40^{o}C may reduce oil viscosity, improve cold-flow trough fuelling system and its injection, fuel spray penetration and atomisation quality. On the other part, extremely low cetane number (8) of ethanol and its high auto-ignition temperature of 420^{o}C along with a high volatility, three-fold bigger, 910-915 kJ/kg, latent heat for evaporation comparing with that, 297-300 kJ/kg, of petrol and absorbed water content may aggravate auto-ignition of small fuel portions injected under easy loads and low speeds.

On the other hand, the viscosity of RO could be diminished even more effectively by blending it with mineral low octane petrol A-76/80, which is known as being by 4.3% lighter than ethanol. In contrast to ethanol, the miscibility of petrol with RO is excellent and, it is worth noticing, that blends PRO are more stable than ERO and no phase stratification takes place during storage that lets regard them as potential biofuels variety extender. It should also be taken into account that net heating value (42.88 MJ/kg) of petrol is approximately by 60% better relative to that (26.82 MJ/kg) of ethanol and exhibits cetane number ranging from 20 to 25, i.e. three-fold higher relative to ethanol, and auto-ignition temperature slightly lower (300^{o}C) comparing with that of RO (320^{o}C) [8]. Furthermore, the addition of petrol into RO extends range of evaporation temperature from 35 to 195-210^{o}C comparing with a single boiling point (78^{o}C) at the start of the distillation curve of ethanol and this temperature is far below the starting point of distillation curve of rapeseed oil. Mentioned favourable factors may intensify evaporation of blends PRO and preparation of combustible mixture facilitating auto-ignition of heavy, viscous and low volatile oil droplets.

In contrast to ethanol-rapeseed oil blends testing, reliable reference sources reflecting performance efficiency of the diesel engine and its emissions changing behaviour when operating under various loading conditions on three-agent ethanol-petrol-rapeseed oil blends (EPRO) are very limited in the available literature. Cold pressed rapeseed oil was brought from the RME plant “Rapsoila”, Lithuania, which production was started in 2004 with the capacity of 10 000 tons of RME. The properties of the rapeseed oil, ethanol and petrol used for biodiesel tests as well as effect of the addition of considered improving agents into RO on blend’s viscosity have been analysed in more detail in Ref. [9, 10].

Purpose of the research

The purpose of this study is to provide comparative analysis of the effect of simultaneous addition of ethanol and petrol into RO on the brake mean effective pressure, brake specific fuel and energy consumption, brake thermal efficiency, smoke opacity of the exhausts and emission composition changes, including nitrogen oxides NO, NO_2, NO_x, carbon monoxide CO and dioxide CO_2, and total unburned hydrocarbons HC when running the engine alternately on pure rapeseed oil and its 7.5vol% blend with both improving agents applied in equal 50-50vol% proportions over a wide range of loads and speeds.

Objects, experimental apparatus and methodology of the research

Tests have performed on a naturally aspirated, four stroke, four cylinder, direct injection, 59 kW diesel engine D-243 with *D/S* = 110/125 mm, splash volume V_l = 4.75 dm^3 and compression ratio ε =16.0:1. In order to increase flow rate of biofuel blend EPRO7.5 in the fuelling system were installed two joined in parallel fine porous fuel filters. The fuel was delivered by an in line fuel injection pump through five holes injector nozzles with the initial fuel delivery starting at 25^o before top dead centre. The needle valve opening pressure for all injectors was set up to 17.5±0.5 MPa.

Torque of the engine was measured with a three phase asynchronous 110 kW electrical AC stand dynamometer KS-56-4 with a definition rate of ±1 Nm. The revolution frequency of the crankshaft was determined with the universal ferrite-dynamic tachometer TSFU-1 and its counter ITE-1 which guarantees the accuracy of ±0.2%. The fuel mass consumption was measured by weighting it on the electronic scale SK-1000 with a definition rate of ±0.05 g and the volumetric air consumption was determined by the means of the rotor type gas counter RG-400-1-1.5 installed at the air tank for reducing pressure pulsations.

To obtain the base-line parameters, the engine was first operated on pure rapeseed oil. Load characteristics of the engine were taken at crankshaft revolutions of 1400, 1600, 1800, 2000 and 2200 min^{-1} and torque gradually increased from the point that was close to zero up to maximum value of 290-310 Nm with an increment rate of 4-5 Nm. After all load characteristics were taken of the engine performance on RO as a basic fuel, three-agent ethanol (E3.75vol%), petrol (P3.75vol%) and rapeseed oil (RO92.5vol%) blend EPRO7.5 was prepared by pouring both additives in equal 50:50vol% proportions into rapeseed oil container and mixing by hand-splash to avoid phase separation. Having blend EPRO7.5 prepared, similar experiments were conducted over the same range of engine loads and speeds. At every load setting the measurements were taken after temperatures of cooling water and lubricating oil had been stabilised at level of 85-90^oC.

The amounts of carbon monoxide CO (ppm), dioxide CO_2 (vol%), nitric oxide NO (ppm), nitrogen dioxide NO_2 (ppm) and the residual oxygen O_2 (vol%) content in the exhausts were measured with the Testo 33 gas analyser.

The amount of unburned hydrocarbons HC (ppm vol) and the residual oxygen O_2 (vol%) content in the exhaust manifold were determined afterwards with a gas analyser TECHNOTEST Infrared Multigas TANK 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 the accuracy of ±0.1%.

In order to achieve more or less adequate combustion conditions and perform accurate analysis of the effect of blend EPRO7.5 on production of harmful species, their changing behaviour under various speeds was determined for constant air-to-fuel equivalence ratios λ specified for easy, λ = 6.0, medium, λ = 3.0, and heavy, λ = 1.6, loading conditions.

The test results and analysis

Analysis of test results shows real advantages that could be utilized from using three agent blend EPRO7.5 emerge under heavy loading conditions mainly because the considered blend having approximately the same fuel energy content 1.742 MJ/kg accumulated within fuel-rich mixture, $\lambda = 1.6$, ensures brake mean effective pressure by 1.0% higher and 0.8% lower comparing with the respective bmep data, 0.770 and 0.740 MPa, obtained during its operation on pure RO at 1800 and 2200 min^{-1} speeds. However at low 1400 min^{-1} speed the bmep of the fully loaded engine fuelled with blend EPRO7.5 is lower by 9.8% relative to that of RO (0.772 MPa). Comparative reduction of the bmep is even more noticeable, by 13.5% and 64.7%, during operation under medium, $\lambda = 3.0$, and easy, $\lambda = 6.0$, loads because extremely low cetane properties of ethanol (8) and petrol (20-25) do not contribute in having shorter auto-ignition delay and stable performance of the easy loaded engine at low speed.

The brake specific fuel consumption (bsfc) of the engine operating on blend EPRO7.5 at rated 2200 min^{-1} speed changes against that of RO from by 1.1% higher for easy load to lower by 3.7% for heavy loading conditions. In order to evaluate the brake specific energy consumption (bsec) of biofuels tested, the bsfc and net heating values of ethanol, petrol and rapeseed oil, their blending ratios and the contents of fuel bond oxygen were taken into account. Dependencies of the bsec in MJ/kWh as a function of speed determined during engine operation on pure RO and three-agent blend EPRO7.5 for three loading conditions characterised by specific air-to-fuel equivalence ratios $\lambda = 6.0$, 3.0 and 1.6 have been superimposed as shown in graphs of Fig. 1. The simultaneous addition into RO of 7.5vol% of both plenty oxygenated, 34.8%, ethanol and oxygen-free petrol premixed in equal 50:50vol% proportions produces blend EPRO7.5, which differs itself as having by 4.6% higher (11.30%) fuel mass oxygen content and nearly the same 36.72 MJ/kg net heating value as that of pure RO, 36.87 MJ/kg.

As it follows from the analysis of data, the bsec in the case of using composite blend EPRO7.5 is by 45.6%, 17.2% and 9.5% higher for light, medium and heavy loads at low 1400 min^{-1} speed. The biggest increase in the bsec of blend EPRO7.5 was determined for easy load, $\lambda = 6.0$, however differences in the brake specific energy consumptions between both biofuels diminish to 27.0%, 23.2%, 10.1% and 0.5% with speed of 1600, 1800, 2000 and 2200 min^{-1}. Test revealed that the easy loaded engine is sensitive enough to the simultaneous addition of ethanol and petrol into RO and, as an outcome, the bsec values have on average been increased by 0.824, 0.553, 0.479, 0.227 and 0.012 MJ/kWh, respectively, for every 1% point increase of both improvers in the rapeseed oil with the deterioration rate being lower the higher is rotation speed.

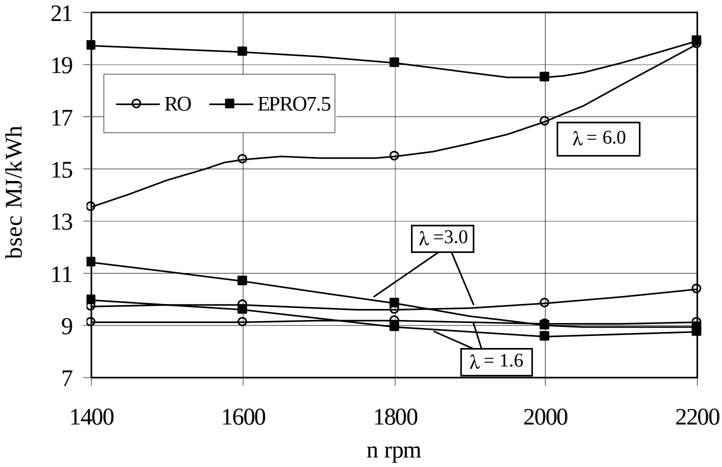

Fig. 1. The brake specific energy consumptions (*bsec*) for various air-to-fuel ratios λ (loads) as a function of engine speed (*n*)

1 pav. Efektyviųjų lyginamųjų energijos sąnaudų (*bsec*) priklausomybės nuo variklio sukimosi dažnio (*n*), esant įvairiems oro ir degalų mišinio santykiams λ (apkrovoms)

When operating under medium load, λ = 3.0, the bsec values of blend EPRO7.5 are also by 17.2% and 2.4% higher for 1400 and 1800 min^{-1} speeds comparing with that of pure RO. However as soon as rotation speed increases to 2000 and 2200 min^{-1}, the bsec of blend EPRO7.5 proceed at by 8.4% and 14.3% lower levels comparing with base-line parameters. The fuel energy consumption behaviour becomes much better after transition to heavy load and the bsec of blend EPRO7.5 from initial by 9.5% and 5.0% higher levels, specific for low 1400 and 1600 min^{-1} speeds, diminishes against that of RO by 3.3%, 5.8% and 4.3% for 1800, 2000 and 2200 min^{-1} speeds. It is obvious from Fig. 1, that in the case of running the engine under moderate and close to maximum loads the bsec graphs of blend EPRO7.5 proceed along speed axis with descending tendencies whereas those of RO suspend at more or less the same level for heavy load increasing slightly for medium and much rapidly for easy loading conditions.

The simultaneous addition of both improvers with a widely differing chemical properties diminishes viscosity of RO, improves fuel injection and penetration into combustion chamber volume, extends evaporation temperature range and elevates auto-ignition under heavy loads stimulating cleaner diffusion burning due to presence of extra ethanol oxygen available within close to stoichiometric fuel-rich zones along with better calorific value of petrol, which maintains cylinder gas temperature and complete combustion of heavy oil fractions. Because of widely diversing properties, i.e. low calorific value of ethanol and its pure miscibility at a bigger amounts offsets high net heating value of oxygen-free petrol and its excellent solubility with rapeseed oil that in the case of using blend EPRO7.5 converts into a higher brake thermal efficiency (0.41-0.42) and lower brake specific energy consumption 8.55-8.75 MJ/kWh of the fully loaded engine operating at 2000-2200 min^{-1} speeds. In this case biofuel energy conversion is better than that obtained in the case of using 7.5vol% of ethanol [9] and 7.5vol% of petrol [10] separately for RO treatment.

The amounts of NO_x emissions depend on diesel engine performance mode and its set up [4], the feedstock oil used for engine fuelling and iodine number [2], the composition and chemical structure of the fatty acids [1], variations in actual fuel injection timing advance and auto-ignition delay caused by changes in physical properties of the biofuel [11]. Since the addition of ethanol and petrol into RO may have influence on biofuel atomisation and distribution in the combustion chamber volume, auto-ignition delay and combustion behaviour of biofuel portions premixed, cylinder gas pressure and temperature, variations in cetane number and actual start of injection may lead to the changes in NO and NO_x emissions.

Analysis of graphs in Fig. 2 shows, that maximum NO_x emissions emanating from blend EPRO7.5 are by 27.7% (1951 ppm), 24.9% (1800 ppm), 16.5% (1812 ppm), 23.8% (2015 ppm) and 2.1% (1546 ppm) higher comparing with that measured from pure RO at corresponding 1400, 1600, 1800, 2000 and 2200 min^{-1} speeds. Percentage changes between NO emissions emanating from both biofuels tested are very similar as that of NO_x emissions. Both NO and NO_x emissions oscillate along speed axis in close vicinity to each other. The higher NO_x emissions have been measured because of oxygenated nature of three agent blend EPRO7.5, whereas significant reduction of NO and NO_x emissions beyond 2000 min^{-1} speed can be attributed to lower brake thermal efficiency and cylinder gas temperature of the engine.

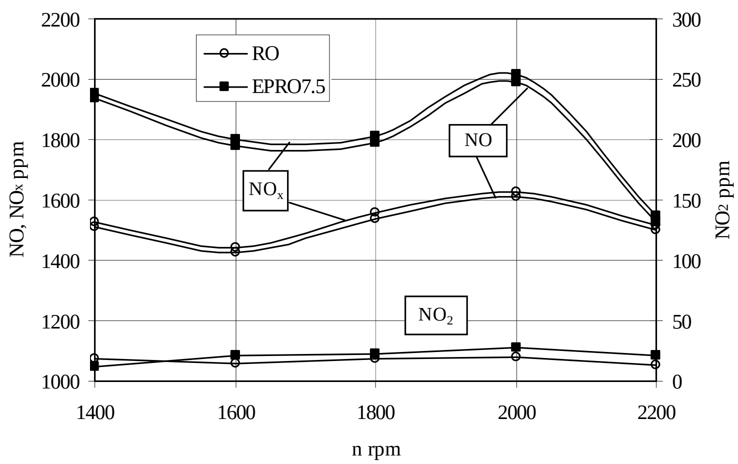

Fig. 2. The maximum NO, NO_2 and total NO_x emissions as a function of engine speed (*n*) emanating from pure RO and blend EPRO7.5

2 pav. Maksimalių NO, NO_2 ir bendrosios NO_x emisijų priklausomybės nuo sukimosi dažnio (*n*), varikliui veikiant rapsų aliejumi ir biodegalų mišiniu EPRO7.5

Considered the NO, NO_2 and NO_x emissions are more or less similar to that specific for blend PRO7.5 [10] and their changing behaviour with speed differs actually from that determined under adequate loading conditions for blend ERO7.5 [9]. The higher NO and NO_x emissions in the case of using blends EPRO7.5 and PRO7.5 have been generated due to the better performance of the diesel engine and a higher maximum cylinder gas pressure and temperature against that produced under unfavourable performance conditions from plenty oxygenated blend ERO7.5 [12]. In spite of having big fuel bond oxygen content, extremely low cetane number of ethanol and its poor calorific value tend to suppress production from blend ERO7.5 of NO and NO_x emissions increasing NO_2/NO_x ratios throughout the whole speed 1400-2200 min^{-1} range from 6.3 to 1.32 times relative to that measured for the easy loaded, $\lambda = 6.0$, engine operating on pure RO [9].

It should be noted, that in the case of running the easy loaded engine on blend EPRO7.5 the comparative NO_2/NO_x ratios have also been determined from 16.9 to 1.31 to times higher at corresponding 1400 and 2200 min^{-1} speed. According Ref. [13], increase in NO_2 emissions under unfavourable performance conditions may occur because of appearance across the combustion chamber volume of cooler regions which may quench the conversion back to NO. As soon as NO_x emissions increase with the load, $\lambda = 1.6$, and NO_2 emissions throughout the whole speed range remain at negligible 12-27 ppm level, the difference between respective NO_2/NO_x ratios vanishes gradually exceeding reference levels from 1.04 to 1.21 times at speeds of 1800 and 2200 min^{-1}. After transition to low 1400 min^{-1} speed, the NO_2/NO_x ratios determined for three agent blend EPRO7.5 against that of pure RO further diminish converting to positive, by 20.6% lower, values due to considerably higher emissions of NO_x (Fig. 2).

Amounts of CO emissions depend on the engine load, speed and percentage of both ethanol and petrol added in the RO. Starting under easy load, $\lambda = 6.0$, and a low speed of 1400 min^{-1} from extremely high 2305 ppm (EPRO7.5) and 332 ppm (RO) levels, CO emissions diminish throughout the whole speed range to 464-377 ppm (EPRO7.5) and 350-400 ppm (RO) for medium, $\lambda = 3.0$, load and remain at reasonable 692 ppm (EPRO7.5) and 596 ppm (RO) levels for heavy, $\lambda = 1.6$, loading conditions at a rated speed of 2200 min^{-1} (Fig. 3).

When running the fully loaded engine on blend EPRO7.5, CO emissions are lower by 28.6% (922 ppm) at low 1400 min^{-1} speed and bigger by 11.0% (772 ppm), 18.8% (621 ppm), 19.7% (607 ppm) and 16.1% (596 ppm), correspondingly, for higher 1600, 1800, 2000 and 2200 min^{-1} speeds relative to base-line parameters given in brackets. The higher CO, NO, NO_2, NO_x emissions and reasonable relative to the initial 23.4% value at 1400 min^{-1} speed increase from 17.1% to 30.8% in smoke opacity generated by the fully loaded engine within 1600-2000 min^{-1} speeds have, probably, been stimulated by deeper combustion of composite blend EPRO7.5 ensuring better biofuel energy conversion efficiency (Fig. 1) whereas the lower CO emission at speed of 1400 min^{-1} could be attributed to the higher fuel bond oxygen content (11.30%) and such result matches well with higher both NO and NO_x emissions at this particular mode.

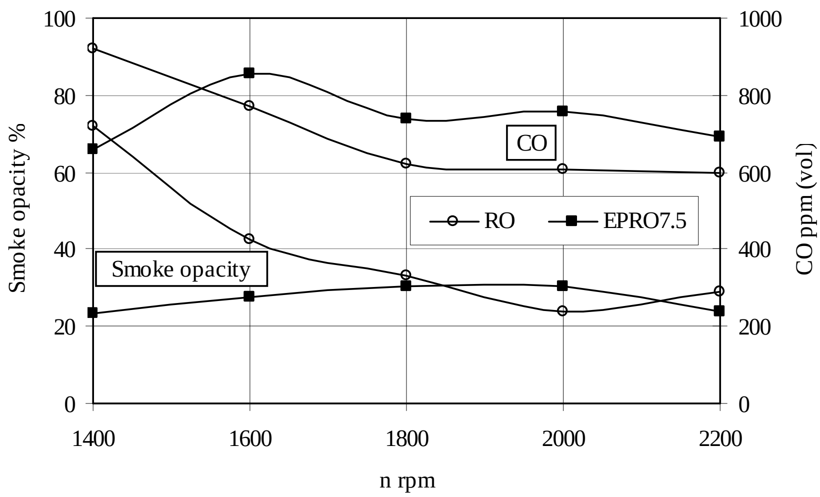

Fig. 3. Dependencies of CO emissions and smoke opacity of the exhausts on engine speed (*n*) when operating alternately on RO and blend EPRO7.5 under heavy load, $\lambda = 1.6$

3 pav. Anglies viendeginio CO emisijos ir deginių dūmingumo kitimas nuo pakaitomis rapsų aliejumi ir biodegalų mišiniu EPRO7.5 maitinamo ir visiškai apkrauto, $\lambda = 1.6$, variklio sukimosi dažnio (*n*)

The final combustion of oxygenated blend EPRO7.5 at late phases of the expansion stroke may lead to the lower by 28.4% CO emission and drastically (by 67.5%) reduced smoke, however it hardly contributes to having better fuel energy conversion efficiency of the loaded engine operating at low 1400 min^{-1} speed [14]. However, because of a better fuel injection pressure and growing cylinder air radial turbulence intensity combustion process accelerates with revolutions so that the bsec of the loaded engine operating on blend EPRO7.5 diminishes at rated 2200 min^{-1} speed along with smoke opacity lower by 17.6% and NO, NO_x emissions almost the same relative to pure RO.

Emissions of HC are higher by 9-12 ppm and CO_2 produced from blend EPRO7.5 amounts 7.9vol% with temperature of the exhausts being nearly the same 510^oC relative to that of RO at rated 2200 min^{-1} performance mode.

Conclusions

1. The test results show that the heavy loaded engine fuelled under the maximum torque mode 1800 min^{-1} and rated 2200 min^{-1} speed with three agent blend EPRO7.5 having approximately the same fuel energy content 1.742 MJ/kg accumulated within fuel-rich mixture, $\lambda = 1.6$, ensures the brake mean effective pressure correspondingly by 1.0% higher and by 0.8% lower comparing with that, 0.770 and 0.740 MPa, obtained during its operation on pure RO.

2. Test revealed that performance of the easy loaded engine is more sensitive to the simultaneous addition of ethanol and petrol into RO and the bsec values have on average been increased by 0.824, 0.553, 0.479, 0.227 and 0.012 MJ/kWh for every 1 % point increase of both improvers at corresponding 1400, 1600, 1800, 2000 and 2200 min^{-1} speed. When operating under heavy load, the bsec of blend EPRO7.5 from initial by 9.5% to 5.0% higher levels for a low speed of 1400 and 1600 min^{-1} diminishes against that of RO by 3.3%, 5.8% and 4.3% for a higher 1800, 2000 and 2200 min^{-1} speeds.
3. The maximum NO_x emissions emanating from blend EPRO7.5 are from 27.7% (1951 ppm) to 2.1% (1546 ppm) higher comparing with that, 1528 ppm and 1514 ppm, measured from pure RO at 1400 and 2200 min^{-1} speed. When operating under easy load, the NO_2/NO_x ratios from blend EPRO7.5 are 16.9 to 1.31 times higher at 1400 and 2200 min^{-1} speed, and when running of the engine under heavy load, $\lambda = 1.6$, they are lower by 20.6% and higher 1.04-1.21 times at corresponding 1400 and 1800-2200 min^{-1} speeds.
4. Carbon monoxide CO emissions and smoke opacity of the exhausts from the fully loaded engine operating on three agent blend EPRO7.5 are lower by 28.6% (658 ppm) and 67.5% (23.4%) at low 1400 min^{-1} speed whereas after transition to rated 2200 min^{-1} speed, CO emissions increase by 16.1% (692 ppm) and smoke opacity diminishes by 17.6% (23.9%) comparing with corresponding data measured from pure RO. In the case of using blend EPRO7.5 emissions of HC are higher by 9-12 ppm, CO_2 amounts 7.9vol% and temperature of the exhausts is nearly the same 510 ^oC as that from pure RO at rated 2200 min^{-1} performance mode.

The local tractor powering with environmental friendly and partially renewable three agent blend EPRO7.5 should be dependent, however, on long-term endurance test results and evaluation of all benefits and detriments disclosed during exploitation.

Acknowledgement

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TRIJŲ KOMPONENTŲ ETANOLIO, BENZINO IR RAPSŲ ALIEJAUS MIŠINIU VEIKIANČIO TRAKTORINIO DYZELINIO VARIKLIO DARBO RODIKLIŲ IR DEGINIŲ EMISIJOS ANALIZĖ

Santrauka

Straipsnyje pateikta grynu rapsų aliejumi (RO) ir jo 7,5% tūrio mišiniu su etilo spiritu (E) ir benzinu (P), sumaišytu lygiomis 50% ir 50% tūrio dalimis (EPRO7.5), paeiliui maitinamo keturtakčio, keturių cilindrų, tiesioginio įpurškimo, nepripučiamo dyzelinio variklio stendinių bandymų rezultatų analizė. Bandymų tikslas yra ištirti bendrą spirito ir benzino priedų įtaką lyginamajam efektyviajam slėgiui (bmep), lyginamosioms efektyviosioms degalų masės (bsfc) ir energijos (bsec) sąnaudoms, efektyviajam naudingumui (bte) ir emisijos pokyčiams, įskaitant NO, NO_2, NO_x, CO, CO_2, HC ir deginių dūmingumą.

Trijų komponentų mišiniu EPRO7.5 maitinamo ir maksimaliai apkrauto, $\lambda = 1.6$, variklio išvystomas lyginamasis efektyvusis slėgis, esant maksimalaus sukimo momento 1800 min^{-1} ir vardiniams 2200 min^{-1} sūkiams, yra atitinkamai didesnis 1,0% ir mažesnis 0,8% palyginti su gryno RO atveju. Esant vardiniams 2200 min^{-1} sūkiams, lyginamosios efektyviosios degalų sąnaudos kinta, palyginti su baziniu (RO) variantu, nuo didesnio 1,1% lygio, esant mažai apkrovai $\lambda = 6,0$, iki mažesnio 3,7% lygio, esant maksimaliai apkrovai. Apkrauto variklio lyginamosios efektyviosios energijos sąnaudos MJ/kWh, esant 1400 ir 1600 min^{-1} sūkiams, nuo pradinio 9,5% ir 5,0% didesnio lygio palyginti su RO atveju, sūkiams padidėjus iki 1800, 2000 ir 2200 min^{-1}, atitinkamai sumažėja 3,3%, 5,8% ir 4,3%. Biodegalų mišiniu EPRO7.5 maitinamo variklio maksimalus efektyvusis naudingumo koeficientas yra didesnis 0.41-0.42 palyginti su RO (0.39), esant 2000 ir 2200 min^{-1} sūkiams.

Varikliui veikiant 1400-2200 min^{-1} sūkių dažniu, trijų komponentų biodegalų mišinio EPRO7.5 generuojama maksimali NO_x emisija yra nuo 27,7% (1951 ppm) iki 2,1% (1546 ppm) didesnė palyginti su 1528 ppm ir 1514 ppm gryno RO naudojimo atveju. Maksimaliai apkrauto variklio anglies viendeginio CO emisija ir deginių dūmingumas yra 28,6% (658 ppm) ir 67,5% (23.4%) mažesni, esant mažiems 1400 min^{-1} sūkiams, tuo tarpu sūkius padidinus iki vardinių 2200 min^{-1}, CO emisija padidėja 16,1% (692 ppm) ir deginių dūmingumas sumažėja 17,6% (23,9%) palyginti su atitinkamais rapsų aliejumi maitinamo variklio rodikliais. Varikliui veikiant trijų komponentų biodegalų mišiniu EPRO7.5 vardiniu 2200 min^{-1} režimu, nesudegusių angliavandenilių HC emisija yra didesnė 9-12 ppm, CO_2 susiformuoja 7,9% tūrio ir deginių temperatūra pakyla iki apytikriai to paties 510°C lygio kaip ir naudojant gryną rapsų aliejų.

Dyzelinis variklis, rapsų aliejus, etilo spiritas, benzinas, efektyvieji rodikliai, deginių emisija, dūmingumas

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АНАЛИЗ РАБОЧИХ ПОКАЗАТЕЛЕЙ И ЭМИССИИ ОТРАБОТАВШИХ ГАЗОВ ТРАКТОРНОГО ДВИГАТЕЛЯ, РАБОТАЮЩЕГО НА ТРЁХ КОМПОНЕНТНОЙ СМЕСИ ЭТИЛОВОГО СПИРТА, БЕНЗИНА И РАПСОВОГО МАСЛА

Резюме

В статье анализируются результаты стендовых испытаний рабочих показателей и эмиссии отработавших газов четырехтактного, четырёх цилиндрового, безнадувного с непосредственным впрыскиванием тракторного двигателя работающего поочередно на чистом рапсовом масле (RO) и его 7,5% смеси с этиловым спиртом (E) и бензином (P), смешанных одновременно в равных 50% и 50% пропорциях по объему (EPRO7.5). Целью работы является исследование совместного влияния прибавок спирта и бензина в рапсовое масло на эффективное удельное давление (bmep), удельный эффективный массовый (bsfc) и энергетический (bsec) расходы топлива, коэффициент полезного действия (bte) и изменения эмиссии, включая NO, NO_2, NO_x, CO, CO_2, HC и дымность отработавших газов.

При работе на режимах максимального крутящего момента 1800 $мин^{-1}$ и номинальной 2200 $мин^{-1}$ частоте вращения трёхкомпонентной смесью EPRO7.5 питаемый двигатель на полной, λ = 1,6, нагрузке развивает эффективное удельное давление соответственно большее на 1,0% и меньшее на 0,8% по сравнению с его работой на чистом рапсовом масле. На номинальной 2200 $мин^{-1}$ частоте вращения, эффективный удельный массовый расход топлива варьирует по сравнению с базовым (RO) вариантом от большего на 1,1% уровня при малой нагрузке до меньшего на 3,7% уровня при большой нагрузке. Эффективный удельный расход энергии топлива в МД/кВч на полной нагрузке двигателя и частотах вращения 1400 и 1600 $мин^{-1}$ от начального на 9,5% и 5,0% большего уровня вследствие повышения частоты вращения до 1800, 2000 и 2200 $мин^{-1}$ оказывается меньшим на 3,3%, 5,8% и 4,3% соответственно по сравнению с базовым (RO) вариантом. При работе двигателя на смеси EPRO7.5 и частотах вращения 2000 и 2200 $мин^{-1}$, максимальный коэффициент полезного действия обеспечивается больший 0.41-0.42 по сравнения с базовым RO вариантом (0.39).

В случае питания двигателя трех компонентной смесью EPRO7.5 на частотах вращения 1400-2200 $мин^{-1}$, максимальная NO_x эмиссия генерируется от 27,7% (1951 ppm) до 2,1% (1546 ppm) большей по сравнению с 1528 ppm и 1514 ppm выделяемой рапсовым маслом. При работе на полной нагрузке и малой 1400 $мин^{-1}$ частоте вращения, CO эмиссия и дымность отработавших газов оказываются меньшими на 28,6% (658 ppm) и 67,5% (23,4%). Дальнейшее увеличение частоты вращения до номинальной 2200 $мин^{-1}$,

влечет за собой увеличение CO эмиссии на 16,1% (692 ppm) и уменьшение дымности отработавших газов на 17,6% (23,9%) по сравнению с базовым (RO) вариантом. На номинальном 2200 мин$^{-1}$ режиме работы двигателя на биотопливе EPRO7.5 эмиссия углеводородов HC оказывается большей на 9-12 ppm, углекислого газа CO_2 составляет 7,9% по объему и температура отработавших газов повышается до примерно такого же 510^{o}C уровня, как и в случае применения чистого рапсового масла.

Дизельный двигатель, рапсовое масло, этиловый спирт, эффективные показатели, эмиссия, дымность отработавших газов.