Evaluation of effects of biofuels blends on performance and emissions of diesel engine

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Abstract: *Growth of the economy and living standards of the population increase the need of people's and goods transportation by sea, railroads, the air, and highways. As a result, increases the need to use more ships, trains, airplanes, heavy-duty trucks, self-powered machines, city busses, and light-duty passenger cars. Unavoidably increases the demand of the fuel to be consumed, however the natural oil-resources are largely exhausted over hundreds of years. Moreover, the increased consumption of a fossil-origin fuel creates the urgent environment pollution problems and climate change. The automotive air-pollution problem emerged already aim of this article was to investigate the influence of three-component fuel on the efficiency and emission performance of a diesel engine. The results obtained during the research are presented, which are investigated with a single-cylinder diesel engine "ORUVA F1L511". The study examines diesel fuel and fuel blends J5Bu5, J5Bu10 and J5Bu15. The results obtained in the study are comparable. Engine load characteristics were recorded at n = 2000 rpm. The study found that the lowest carbon monoxide (CO) emissions (163ppm) were obtained by using J5Bu5 fuel blend. Maximum nitrogen oxide (NOx) emissions were obtained with the engine running on diesel fuel (1839ppm). The lowest NOx emission was obtained with the engine running on a three-component J5Bu15 fuel blend (1643ppm). The highest opacity was obtained when the engine was fuelled with 100% diesel fuel and at full load.*

KEYWORDS: DIESEL ENGINE, RAPESEED OIL BIODIESEL, AVIATION FUEL, BUTANOL, PERFORMANCE, EMISSIONS, SMOKE OPACITY

1. Introduction

In 1988, the North Atlantic Treaty Organization (NATO) countries decided to simplify the delivery of petroleum products to the combat zone and improve the interoperability of aircraft and land equipment with JP-8 (F-34) military kerosene. In order to put this decision into practice, the NATO Pipeline Committee (NPC) adopted the Single Fuel Policy (SFP) in 2004. The US legislation on the "One Fuel Delivery Policy" stipulates that US military ground vehicles used must be able to work with aviation fuel (JP-8). JP-8 petroleum-based fuel is very similar in specification to the commercially available Jet A-1 fuel. Jet A1 fuel is a light distillate of complex hydrocarbons such as 50-65% paraffins, 10-20% aromatics and 20-30% naphthenes [1]. Jet (JP-8) fuel is a military kerosene turbine fuel made from civilian (Jet A-1) fuel and widely used by the United States Air Force and Europe. Aviation turbine fuel is extracted almost exclusively from the kerosene fraction of crude oil, the distillation points of which are between the gasoline fraction and the diesel fraction.

The cetane number of a fuel is one of the most important factorsvaffecting the autoignition quality in diesel engines. It was foundvthat the JP-8 and ULSD with similar CN have highly comparable combustion characteristics in a DI compression ignition engine and CN is the paramount characteristic in comparing these fuels.

Authors investigate effects of diesel fuel (B5), turbine type JP-8 fuel and its 5 vol%, 10 vol%, 20 vol%, and 30 vol% blends with rapeseed oil methyl ester (RME) on the start of injection, ignition delay, combustion history, heat release, engine performance, and exhaust emissions. The engine performance parameters were examined at light 15% (1400 rpm) and 10% (2200 rpm), medium 50%, and high 100% loads and the two speeds. They found that the autoignition delay and maximum heat release rate decreased, maximum cylinder pressure, and pressure gradients increased, whereas brake specific fuel consumption changed little and brake thermal efficiency was 1.0–3.6% higher when running with fuel blends J5 to J30 at rated speed compared with the data measured with neat jet fuel. The NOx emissions increased slightly, but the CO, THC emissions, and smoke opacity boosted up significantly when using jet fuel blend J10 with a smooth reduction of unburned hydrocarbons for jet-biodiesel fuel blends with higher CN ratings. Operation at a full (100%) load with fuel blend J10 produced more CO and exhaust smoke, whereas the combustion of identical fuel blend B10 showed the reverse trends reducing both pollutants at both engine speeds [2].

Using fuel blends with the higher content of biodiesel changes the technical properties of the fuel: increase density, viscosity, decrease calorific value, cetane number, freezing temperature, etc. These indicators have the impact on the biofuel supply and injection characteristics, the quality of the combustible mixture that, in turn, has influence on diesel engine performance and ecological indicators [3].

Ethanol, methanol, and butanol are currently the most popular alcoholic fuels used in internal combustion engines around the world. Higher oxygen content in alcoholic fuels than that in mineral fuels may result in lower calorific value of the biofuels. However, these fuels need less air-borne oxygen to burn to burn the fuel completely and thus can contribute better quality of the environment. The elemental composition of alcoholic fuels makes it possible to reduce the amount of smoke (soot), carbon monoxide CO, carbon dioxide CO2 and aldehydes emitted from diesel engine [4]. A study conducted a comparative analysis of performance and emissions characteristics of aviation fuel (Jet A-1) and butanol/Jet A-1 fuel (B10) blend. Authors found that the fuel consumption and specific fuel consumption is slightly higher for blend with butanol, compared to Jet A-1 fuel. This is due to the fact, that lower calorific value for fuel blend. The values of carbon monoxide (CO), carbon dioxide (CO2) and nitrogen oxides (NOx) emissions for fuel B10 blend were slightly lower, compared to the cases of using Jet A-1 fuel [5]. Normal butanol (C4H9OH – 74.0 g/mol) is an alcoholic-origin colourless liquid with a harsh fusel with banana odour, which possess 21.58 wt% of fuel-bound oxygen and differs as having low flash point of 28.9 °C and the boiling point of 117.7 °C at 760 mm Hg. On the one part, n-butanol added to commercial diesel fuel reduces density, viscosity, C/H atoms ratio and provides fuel-bound oxygen that along with good evaporative properties improves both the air and fuel vapours mixing rate and the combustion of fuel blend leading to more environment friendly exhaust. On the other part, the presence of a lighter and oxygenated n-butanol reduces the cetane number, net heating value and thus mass of the fuel consumed per unit of energy developed by an engine. The sensitive interaction between advantages and disadvantages properties of n-butanol added to diesel fuel may lead to ambiguous development trends combustion, heat release rate and engine out emissions [6]. Moreover, the use of bio-based products in fuels is a strategic government resolution in most European countries [7]. The analysis of other works investigations of fuel chemical parameters shows, that from an engine-critical characteristics perspective butanol – hydrogenated vegetable oil – diesel blends are a potential solution [4].

Authors investigate and compare effects of biodiesel-ethanol (BE) and biodiesel-n-butanol (BBu) blends on combustion, performance and emissions of a direct-injection diesel engine. Experiments were conducted on BE5 (5% ethanol and 95% biodiesel, v/v), BE10, BE15, BBu5, BBu10 and BBu15, at five engine loads and at 1800 rpm. They found that blended fuels have adverse effects on engine performance especially at low load, with the BE blends having more adverse effects than the BBu blends. Moreover, on average of the five engine loads, the BBu and BE blends increase CO emission by 13.7% and 22.8% and HC emission by 5.6% and 29.2%, respectively; but reduce NOx emission by 6.5% and 28.0%, particle mass concentration by 20.7% and 20.6% and particle number concentration by 22% and 21%, respectively. Overall, the BE blends are more effective in reducing particulate and NOx emissions but the BBu blends would lead to less increase in CO and HC emissions [8].

A study conducted a comparative analysis of fuel properties, performance, emissions and combustion characteristics of biodiesel produced from waste cooking oil (B100), along with a binary blend of biodiesel–diesel (B20) and ternary blends of biodiesel–diesel–butanol as substitutions to diesel fuel. Although biodiesel and n-butanol have some negative impacts on engine performance parameters, they generally positively affect exhaust emission parameters compared to euro diesel. Addition of n-butanol decreased some of the fuel thermo-physical properties such as density, viscosity and flash point. The average decreases in brake power when n-butanol was added were 6.17%, 7.49% and 11%, respectively, coupled with increases in specific fuel consumption of 6.25%, 8.96% and 14.29%, respectively. The addition of n-butanol decreased exhaust gas temperatures, CO, HC, NO and smoke emissions [9].

The purpose was to study the effects of three-component fuel blends on performance, and exhaust emissions of a diesel engine.

2. Preconditions and means for resolving the problem

Experimental research was carried out in the fuel equipment testing laboratory of the Power and Transport Machinery Engineering Institute at the Faculty of Agricultural Engineering of Vytautas Magnus University − Agricultural Academy. For stroke, one cylinder, direct injection, air cooled „ORUVA FL 511" diesel engine was used for these experiments.

At first, engine tests have been conducted by using jet-biodiesel fuel blend were prepared by mixing RME and JP-A1 fuel in the following proportion by volume 5/95 (J5). After all load characteristics were taken of the engine performance on jet-biodiesel fuel (J5), three blends with jet-biodiesel fuel (J5) and n−butanol (Bu) were prepared by mixing in various volumetric ratios 95% J5 and 5% Bu (J5Bu5), 90% J5 and 10% Bu (JBu10) and 85% J5 and 15% Bu (J5Bu15). The properties of the tested fuels and its blends are presented in Table 2.

The engine torque was measured with an eddy current dynamometer with a definition rate of ±0.1 Nm and the rotation speed with the mechanical meter with a definition rate of ±2 rpm.

The amounts of nitric oxide NO (ppm), nitrogen dioxide NO_2 (ppm), carbon monoxide CO (ppm) and total unburned hydrocarbons HC (ppm) in the exhausts were measured with the Testo 350 XL gas analyser. Total emissions of nitrogen oxides NOx were determined as a sum of both NO and NO_2 gases. Total NOx emissions were determined as a sum of both NO and NO_2 pollutants with an accuracy of ±5 ppm.

The exhaust opacity (%) was measured with a Bosch RTT 100/RTT 110 opacity-meter with an accuracy of ±0.1°.

Table 1. *Properties of JP-A1 fuel, rapeseed oil methyl ester (RME) and n-butanol*

Property parameters	JP-A1	RME	n-butanol
Density at 15°C, kg/m3	797.2	884.7	802
Kinematic viscosity at 40 °C, mm^2/s	4.0	4.8	2.63
Lubricity, corrected wsd, 1.4 lm at 60 °C	611	205	591
Cetane number	42,3	53.4	25
Oxygen content, max wt. %	−	10.9	21,58
Carbon-to-hydrogen ratio (C/H)	6.13	6.48	4.80
Net heating value, MJ/kg	43.30	37.23	33.08
Stoichiometric air/fuel ratio, kg/kg	14.84	12.62	11.2

The engine characteristics were determined when it was driven by a gradually increasing load and a constant engine speed of 2000 rpm. To improve reliability of the measured data the tests have been repeated no less than three times.

3. Solution of the examined problem

Fig. 1 shows the fuel consumption per hour and brake specific fuel consumption (bsfc) variations as a function of engine load. Alterations of the combustion process has effect on engine economy Under the same operating conditions, the fuel consumption, when the engine has been operating on jet-biodiesel fuel and its blend with n−butanol, has been little higher compared to the engine operating on jet-biodiesel fuel (J5) blend. It has to be noted, that the change of bsfc has been decreasing while the engine load was increasing (Fig.1). It is seen, when engine running on oxygenated biofuel blends J5Bu5, J5Bu10 and J5Bu15, at low load, the brake specific fuel consumption slightly increased by 1.1 %, 2.3 % and 4.5 %, respectively. When operating on biofuel J5Bu15 blend, the brake thermal efficiency of the diesel engine, decreases by 1 % (Fig.2).

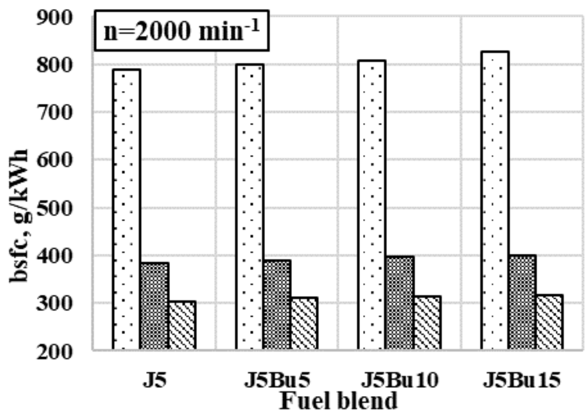

Fig. 1. *The fuel consumption per hour (B_d) and brake specific fuel consumption (bsfc) as a function of engine load at 2000 min^{-1}*

At full engine load, the brake specific fuel consumption changing tendencies remain similar. When operating on the three-component biofuel J5Bu5 – J5Bu15 blends, bsfc increased by 2.4–4.1 %, respectively, in comparison with engine running on fuel J5 blend. The increased fuel consumption of biofuel J5Bu5 – J5Bu15 blends may be attributed reasonably to the lower net heating value of oxygen blends. In case of using the three-component biofuel J5Bu5 – J5Bu15 blends, the brake thermal efficiency decreased by 0.4–1 % in comparison to the engine running on fuel J5 blend. The decrease of the brake thermal efficiency in this case can be explained by the fact that is the mostly affected by their reduced cetane number and the larger latent heat of vaporization of butanol as the latter suppresses the auto ignition and combustion processes in the cylinder.

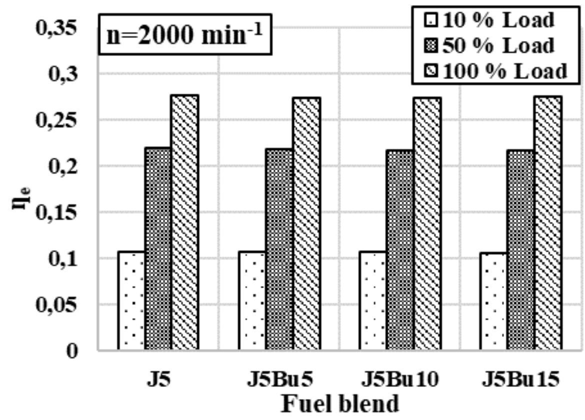

Fig. 2. *Brake thermal efficiency (η_e) and nitrogen oxide (NO_x) as a function of engine load at 2000 min^{-1}*

The nitrogen oxides are formed outside the flame front at high temperatures, with free nitrogen atoms reacting with excess oxygen in the combustion chamber by a complex chain reaction. The total emissions of nitrogen oxides amount in the combustion depends more on the maximum process temperature, because the reaction is endothermic and not directly related to the combustion processes of the mixture. The variation of total emissions of nitrogen oxides (NO_x) with as a function of engine load and different fuel blends is presented in Fig. 2. When the engine is running at the average engine load, using of oxygenated biofuel blends J5Bu5, J5Bu10 and J5Bu15, the total emissions of nitrogen oxides reduces by 7.9 %, 5.6 % and 15.8, respectively.

The total emission of nitrogen oxides scales up when load of the engine increases. In case at full engine load and use biofuel J5Bu5, J5Bu10 and J5Bu15 blends, the total emission of NO_x decreased by 3.5 %, 9.2 % and 10.6 %, respectively, in comparison with engine running on fuel J5 blend. The decrease in total emission of nitrogen oxides can be explained by the lower gas pressure and temperature in the cylinder as the combustion and heat release processes moved towards the direction of the expansion stroke. The pressure and temperature of the gas burning in a large volume of the cylinder are lower which in turn conditions the lower degree of nitrogen oxides emission. Butanol–diesel blends also show this behaviour, as butanol concentration increased, the NOx, and CO emissions decreased, while unburned HC emissions, BSFC, and BTE increased as compared to diesel [10].

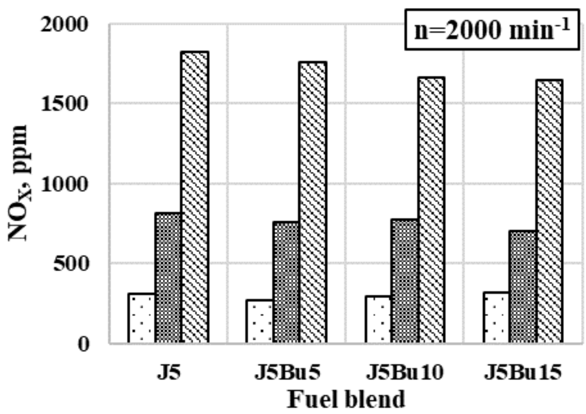

Fig. 2. *Brake thermal efficiency (η_e) and nitrogen oxide (NO_x) as a function of engine load at 2000 min^{-1}*

Carbon monoxide is formed at local locations in the combustion chamber where oxygen is completely lacking for the combustion reaction. Incompletely burned carbon atoms reduce the thermal energy conversion efficiency of fuels and increase carbon monoxide emissions. Ineffective combustion and low chamber temperatures release the carbon monoxide and the unburned hydrocarbons emissions.

The dependencies of carbon monoxide (CO) emission of engine load is shown in Fig. 3. When the engine is running at low load and using the three-component biofuel J5Bu5, J5Bu10 and J5Bu15 blends, the (CO) emission increases by 19–26 %, respectively, compared to the engine running on fuel J5 blend. In case at full engine load and using rich oxygenated blends J5Bu10 and J5Bu15, the carbon monoxide emission decreased by 13.3 % and 14.5 % in comparison to the engine running on fuel J5 blend. When operating on biofuel blend J5Bu5, the CO emission increases by 3 %. Similar trends were obtained using n-butanol as an additive in a heavy-duty diesel engine with 5%, 10%, 15% of n-butanol content using multiple injections. Similar results showed that n-butanol addition decreased soot and CO emissions, but did not have a serious impact on BSFC [11].

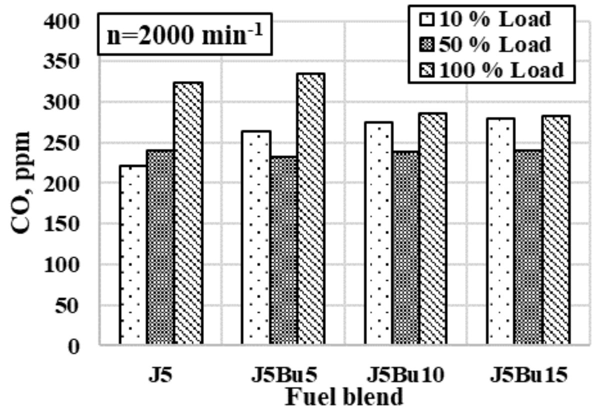

Fig. 3. *Dependencies of carbon monoxide (CO) and smoke opacity of the exhaust on engine load at 2000 min^{-1}*

The soot formation be able to progress at local locations in the fuel-saturated combustion chamber during pyrolysis of hydrocarbons. The smoke opacity of diesel engines depends on the cetane number of the fuel, the chemical composition, the amount of aromatic hydrocarbons, the fuel injection and the quality of the combustible mixture, the diffusion process in the chamber and the complex mechanism of soot particle formation and their combustion burn reaction rate. Fig. 3 shows dependencies of smoke opacity of the exhaust of engine load.

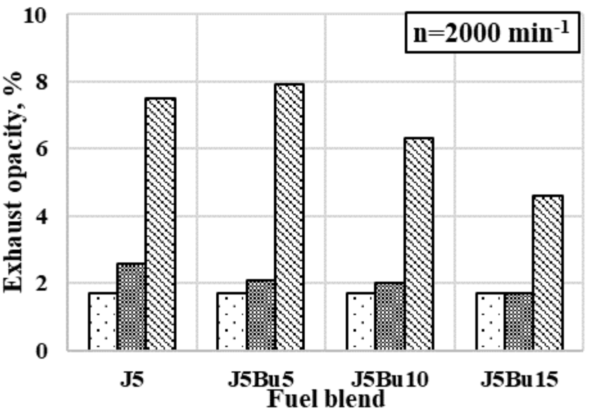

Fig. 3. *Dependencies of carbon monoxide (CO) and smoke opacity of the exhaust on engine load at 2000 min^{-1}*

At low engine load, the smoke opacity remained lower in case of using all J5, J5Bu5, J5Bu10 and J5Bu15 fuel blends. The smoke opacity produced from biofuels J5Bu5, J5Bu10 and J5Bu15 fuel blends sustained at lower levels over the average engine load. When running the engine on biofuel blends J5Bu10 and J5Bu15 at full load, the smoke opacity decreased by 19 % and 63 %, respectively, compared to the cases of using J5 fuel blend. The lower smoke matches well with the test results findings of other researchers [12]. The effects of oxygenated fuel blends on the auto-ignition delay, combustion reactions, engine efficiency, smoke and exhaust emissions depend on the composition of the tested fuel blends, their chemical and physical properties as well as on engine load, speed, availability of air-born oxygen and temperature conditions inside the cylinder

Conclusions

1. The brake mean fuel consumption using three-component fuel blends increased across at over the whole load range. At full engine load, the three-component fuel J5Bu5, J5Bu10, and J5Bu15 blends, the break mean fuel consumption increased by 2.4 %, 3.5 %, and 4.1 %, respectively, compared to fuel J5 blend.
2. Using a three-component biofuel J5Bu15 blend, the break thermal efficiency was 1 % lower, compared to the engine running on fuel J5 blend, at full engine load.
3. The jet-biodiesel fuel (J5) blend developed the highest (1817 ppm) total emissions of nitrogen oxides. At full engine load and using different biofuel J5Bu5, J5Bu10 and J5Bu15 blends, the most environmentally and human harmful total emissions of nitrogen oxides decreased by 3.5 %, 9.2 % and 10.6 %, respectively.
4. When the engine running at low load, the highest the carbon monoxide emissions were obtained with the engine running on biofuel J5Bu15 blend (279 ppm) and the lowest using the fuel J5 blend (221 ppm).
5. At the medium engine load using the three-component fuel J5Bu5, J5Bu10 and J5Bu15 blends, the smoke opacity was 23 %, 30 % and 52.9 % lower, compared to the engine running on fuel J5 blend.

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