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Reduction of the Gaseous Emissions in the Marine Diesel Engine Using Biodiesel Mixtures

Michal Puškár [1,*], Melichar Kopas [1], Dušan Sabadka [1], Marek Kliment [1] and Marieta Šoltésová [2]

1 Faculty of Mechanical Engineering, Technical University of Košice, Letná 9, 042 00 Košice, Slovakia; melichar.kopas@tuke.sk (M.K.); dusan.sabadka@tuke.sk (D.S.); marek.kliment@tuke.sk (M.K.)

2 Faculty of Mining, Ecology, Process Control and Geotechnology, TU Košice, Park Komenského 19, 040 01 Košice, Slovakia; marietta.soltesova@tuke.sk

* Correspondence: michal.puskar@tuke.sk

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Abstract: Taking into consideration the quality of air, it is necessary to ensure a continued reduction of the gaseous emissions that are produced by the maritime transport. The most effective solution of this serious worldwide problem is application of a suitable fuel mixture, which contains a bio-component, i.e. the biofuel. The presented scientific study is focused on influence of the biofuels on production of the gaseous emissions in the case of a diesel auxiliary engine, which is used in the ship transport. There were created various fuel mixtures with different content of the bio-component in order to investigate their emission characteristics. The individual experimental measurements were performed at the different engine loading levels and using a variable engine speed spectrum. The obtained results demonstrated a significant influence of the fuel mixtures on the whole combustion process, on the heat release process, on the pressure time behaviour as well as on the engine emission characteristics.

Keywords: reduction; gaseous emissions; biodiesel mixtures

1. Introduction

It is a well-known fact that a large amount of the international transport of various goods and materials is carried out by the sea. However, it is also necessary to emphasize such reality that the sea transport is characterized by a high fuel consumption as well as by production of a large volume of the harmful gaseous emissions. There is often neglected a relevant fact that the ship transport causes more serious and more dangerous air pollution than the standard motor vehicles. With regard to these negative circumstances, the International Maritime Organization (IMO) determined the new internationally valid regulations in order to reduce the increasing amount of the most dangerous air pollutants, namely the sulphur oxides and the nitrogen oxides.

The diesel engines installed in the trans-continental ships are burning the heavy fuel oils (HFO) both in the main driving engines and in the auxiliary diesel engines. This kind of fuel produces a large amount of the harmful gaseous emissions. In the view of the above mentioned facts, it is necessary to look for other solutions, such as biodiesel. Biodiesel is a renewable natural fuel source with only a minimum content of sulphur and aromatic hydrocarbons, as well as it is characterised by a high value of the cetane number and biodegradability [1–3]. At the same time, it does not require constructional modification of the diesel engine itself.

Various studies were elaborated in order to investigate the real environmental impacts of the gaseous emissions caused by biodiesel fuel. The results gained from the performed studies show a positive fact that the values of sulfur, CO emissions, unburned hydrocarbons, and particulate matter were significantly reduced in the exhaust gases compared to the standard diesel fuels. Biodiesel is soluble in normal diesel oil and for that reason it can be combined with diesel oil in any proportion.

All the studies concerning application of biodiesel fuels were focused only on diesel engines working in motorcars [4–10]. However, it is also necessary to investigate gaseous emissions which are emitted from the auxiliary diesel engines installed in ships as diesel-powered electric generators. Another considerable problem is a lack of the scientific research studies describing the relation between the NO_2 and NO emissions that are caused by combustion of the fuel mixture "biodiesel–diesel oil" [11–14].

The main task of the performed research was to analyse the influence of various mixtures of biodiesel and diesel fuels on the combustion process and on the NO_X emissions in the case of diesel combustion engines that are installed in the ships.

2. Experimental Engine and Measuring Specifications

2.1. Experimental Engine and Diesel Mixtures

The testing experimental engine, which was applied during realisation of the experiments, is an auxiliary six-cylinder diesel engine (Figure 1). The technical data of this engine are presented in Table 1. The individual diesel fuel mixtures were created by mixing of the ULSDF (Ultra Low Sulphur Diesel Fuel) with the biodiesel using various mixing ratios. The tested engine was connected to a test stand [15–17].

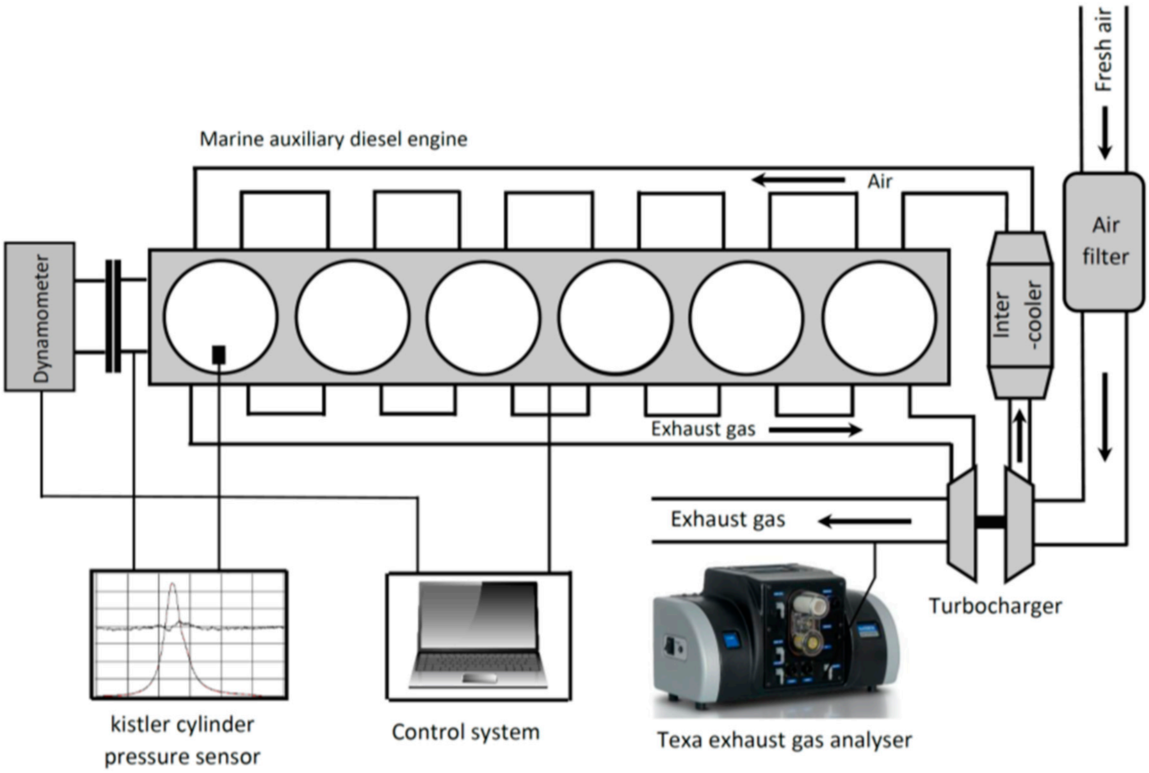

Figure 1. Experimental engine.

Table 1. Technical data of the engine.

Model	6TWGM
Type	6 cylinders, direct injection
Compression ratio	17.0:1
Bore × stroke	100 × 127 mm
Displacement	5.99 L
Rated output	125.5 kw
Engine speed	1500 rpm
Air intake way	Turbocharged, air to water cooled

The ULSDF, which was used during testing, contained less than 10 ppm of sulfur. Parameters of the applied biodiesel are in accordance with the European standard EN 14214 (Table 2).

Table 2. The ULSDF and biodiesel specifications.

Specification	Biodiesel	ULSDF
Density, 15 [kg/m^3]	860–900	810–850
Viscosity (40 °C) [mm^2/s]	3.5–5.0	2.0–4.0
Cetane number	Min.51	Min.48
Sulphur content [mg/kg]	<10	<10
Heat of evavoration [kJ/kg]	250–290	282–338
Flash point [°C]	101	82
Carbon content	81.5	97.1

The tested fuels were obtained by mixing of the ULSDF with the biodiesel, applying various mixing ratio values, namely, 0%, 30%, 70%, and 100%, using the following marking: BU (0:100), BU (30:70), BU (70:30), and BU (100:0), respectively, whereby the letter B means biodiesel and the letter U means the ULSDF. There were also tested diesel engine fuels with other ratios between the biodiesel and the ULSDF, but with regard to the main goal of this study, the above-mentioned fuel mixing ratios were the most suitable. The first type of the tested fuel was the pure ULSDF and the last tested fuel was the pure diesel oil. The fuel consumption of the tested engine was measured for each one of the fuels. The operational conditions during the measuring process are summarized in Table 3.

Table 3. Fuel consumption (FC).

Engine Speed	Engine Loading	ULSDF FC [kg/h]	B30:U70 FC [kg/h]	B70:U30 FC [kg/h]	Biodiesel FC [kg/h]
	267 Nm (30%)	11.50	11.98	12.47	13.25
1000 rpm	534 Nm (60%)	18.93	19.72	20.99	21.91
	801 Nm (90%)	26.85	27.98	28.83	29.71
	321 Nm (30%)	14.52	14.84	15.84	16.59
1500 rpm	642 Nm (60%)	24.68	25.03	26.64	27.12
	963 Nm (90%)	31.72	32.98	34.70	35.48

2.2. Conditions of Measuring Process

The pressure inside the cylinder was measured using the Kistler measuring equipment, which contains a pressure converter mounted in the first cylinder of the given engine [18–21].

The pressure sensor was connected with the amplifier as well as with the sensor of crankshaft angular displacement. This arrangement enabled measuring the pressure values in the cylinder within the 0.5-degree range of the crankshaft angular displacement. The emissions of NO_X were monitored by means of a special measuring system, which was intended for recording of the emissions [22,23].

2.3. Methodology of Measuring Process

The tested engine was operated at two stabilized engine speeds: 1000 rpm or 1500 rpm and at different engine loading levels (Table 3). The cooling water temperature was maintained between 75 °C and 85 °C. The lubricating oil temperature was kept between 90 °C and 100 °C, depending on the operational conditions. The values of engine fuel consumption, exhaust gas temperature and NO_X emissions were continuously monitored in three-minute intervals, whereby the measured results were averaged.

3. Results and Discussion

3.1. Influence of Various Fuel Mixtures on Output Characteristics

The average values of the measured data for various fuel mixtures are given on Figures 2–7. More than 100 measuring cycles were performed in order to reduce in this way an influence of random changes during the experiment [24–26]. It is visible from Figures 4 and 7 that the value of pressure inside the cylinder decreased with higher engine operational loading in the case of increasing proportion of biodiesel in the experimental fuel. The curves, which describe the intensity of heat generation, are various in the operational regime utilizing the ULSDF and the biodiesel fuel mixture. The pressure value inside the cylinder grew more rapidly for the fuel mixture biodiesel–ULSDF compared to the clean ULSDF. The cetane number that belonged to the biodiesel and also the value of flame speed were higher in comparison with ULSDF. The speed of heat release was reduced with the increasing amount of biodiesel in the tested fuel mixtures and the ignition delay decreased if the volume of the biodiesel in the tested fuel was higher.

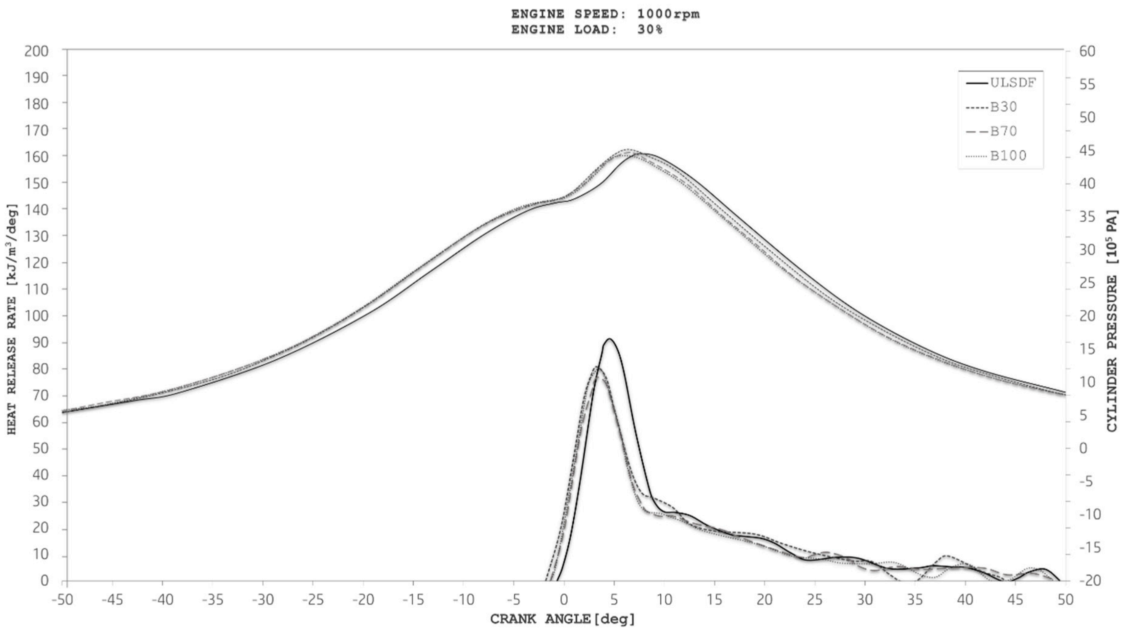

Figure 2. The dependence of fuels on the heat release rate and cylinder pressure (1000 rpm/30%).

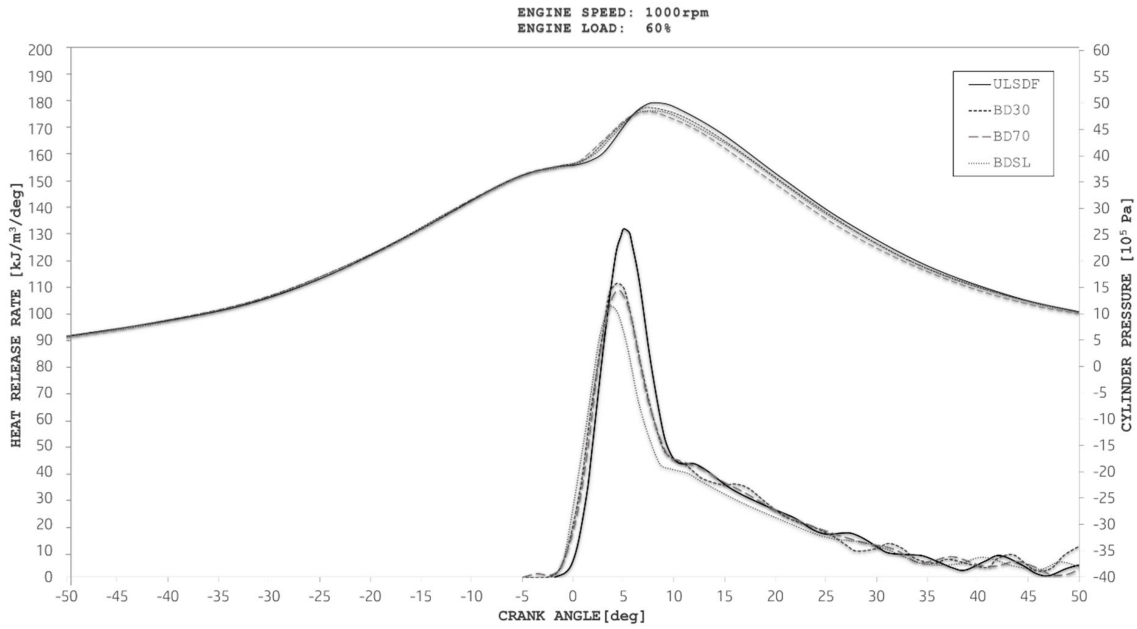

Figure 3. The dependence of fuels on the heat release rate and cylinder pressure (1000 rpm/60%).

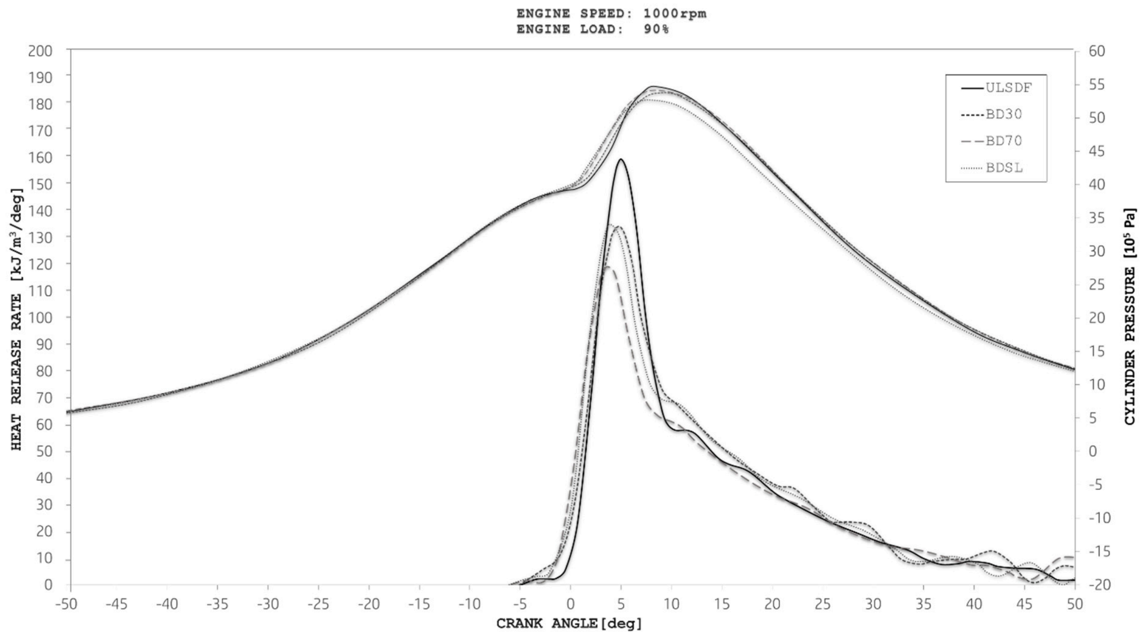

Figure 4. The dependence of fuels on the heat release rate and cylinder pressure (1000 rpm/90%).

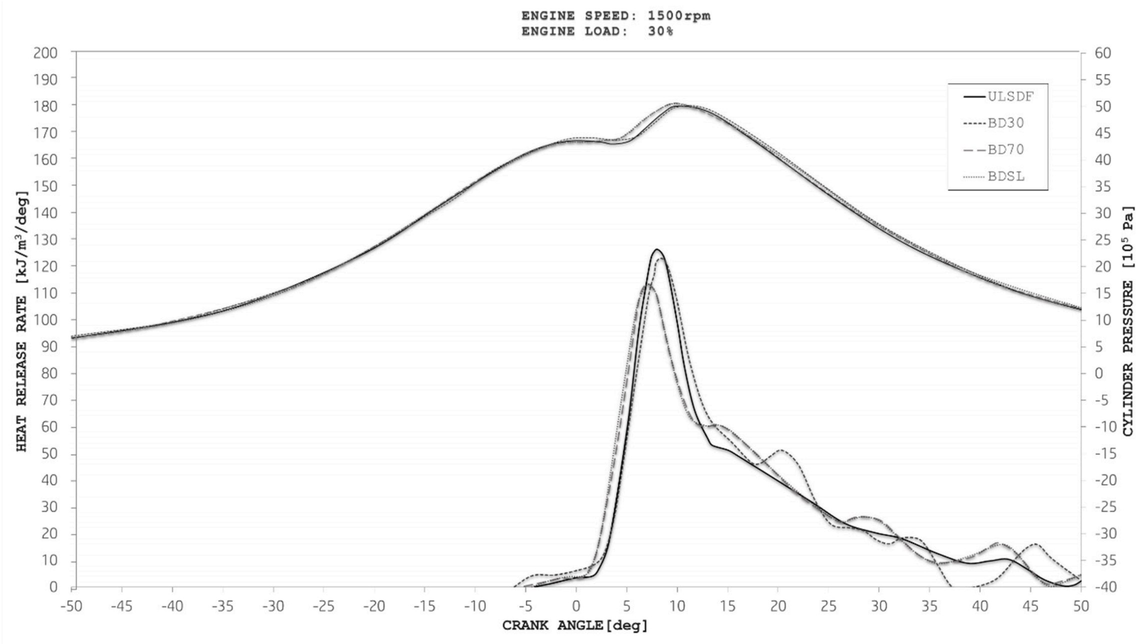

Figure 5. The dependence of fuels on the heat release rate and cylinder pressure (1500 rpm/30%).

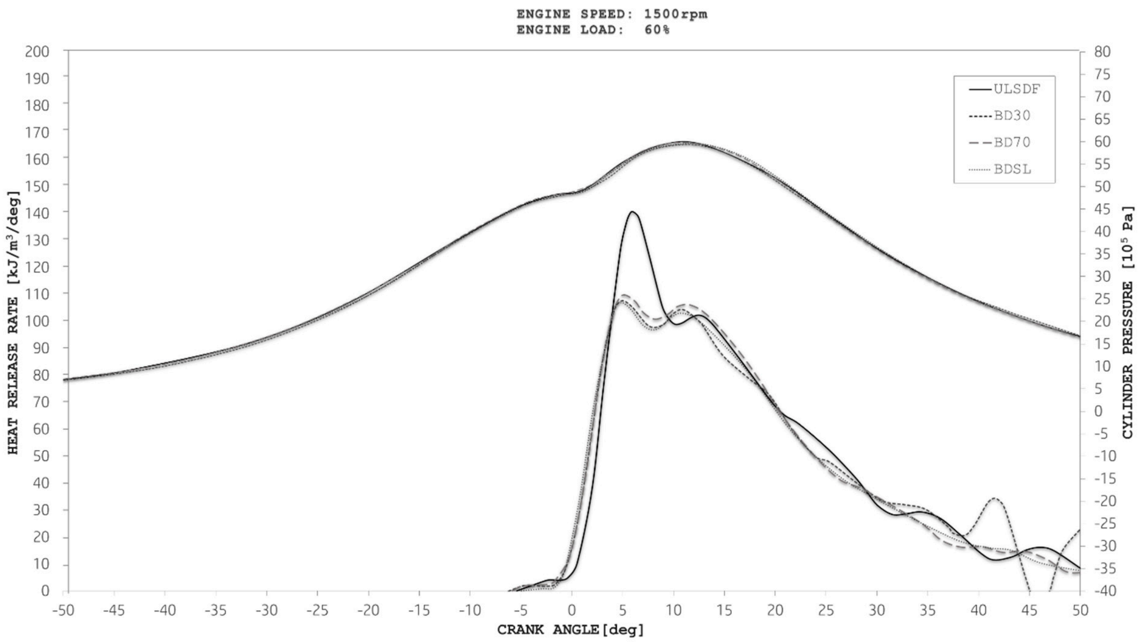

Figure 6. The dependence of fuels on the heat release rate and cylinder pressure (1500 rpm/60%).

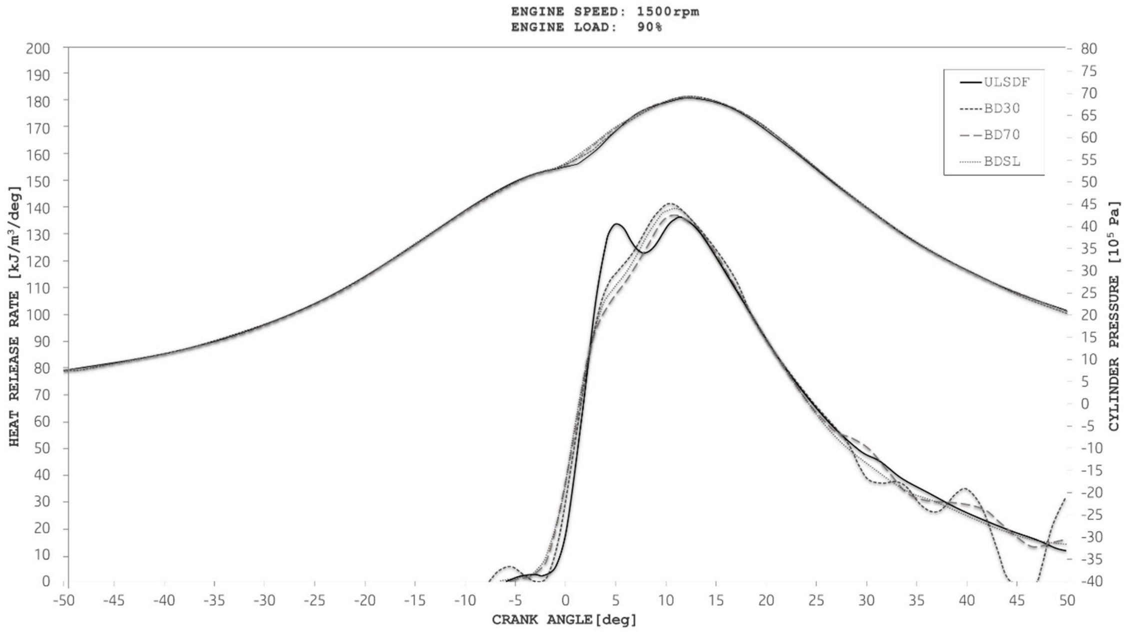

Figure 7. The dependence of fuels on the heat release rate and cylinder pressure (1500 rpm/90%).

3.2. Influence of Fuel Mixture Compositions on NO_X Emissions

The NO_X emissions, which belong among the most polluting substances, consist of the following components: the nitric oxide (NO), the nitrogen dioxide (NO_2) and the dinitrogen monoxide (N_2O). The most relevant are the NO emissions, because their amount is more than 60 percent. The portion of the NO_2 emissions is less than 40 percent and volume of the N_2O is negligible. It is evident, from the Figures 8 and 9, that a higher amount of biodiesel in the fuel mixture significantly affects formation of the NO_X pollutants. Higher content of biodiesel in the tested fuel mixtures minimized the NO_X emissions. It is possible to mention a fact as an illustrative example that operation of the tested engine in the ULSDF fuel mode at low engine speed and low operational loading generated approximately 145 ppm of the NO_X gaseous emissions, whereby in the case of pure biodiesel it was only 100 ppm (Figure 8).

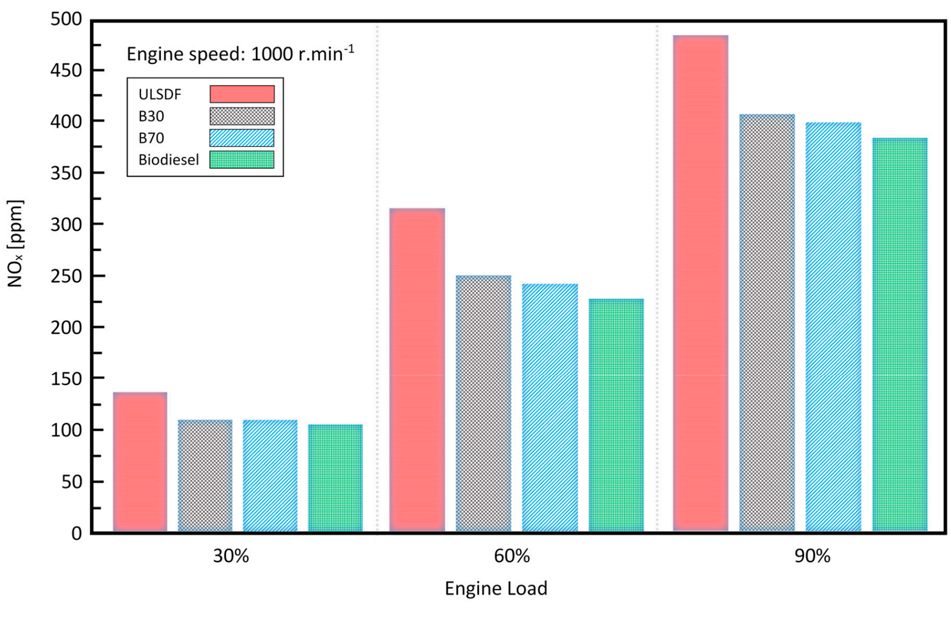

Figure 8. The dependence of testing fuels on the NO_X emissions (1000 rpm).

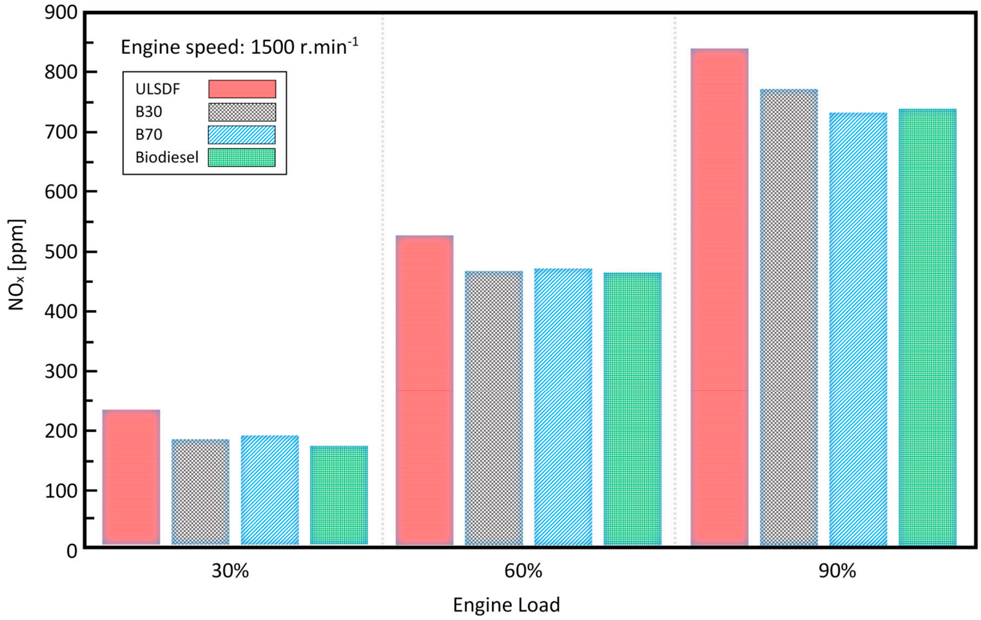

Figure 9. The dependence of testing fuels on the NOX emissions (1500 rpm).

Higher levels of the engine operational loading and engine speed caused an increased amount of the NO_X emissions in the case of all testing fuels. (i.e. up to 850 ppm for ULSDF and 750 ppm for biodiesel) (Figure 9). At the same time, the exhaust gas temperature increased with higher engine speed values and with higher engine operational loading. This fact had a major impact on growth of the NO_X emissions.

3.3. Influence of Fuel Mixture Compositions on NO Emissions and NO_2 Emissions

The Figures 10 and 11 illustrate the influence of various fuel mixtures on the NO emissions and NO_2 emissions. It is interesting that as the engine load increased, the volume of the NO emissions was higher. At the same time, however, these emissions were minimized with increasing amount of biodiesel in the tested fuels. Higher engine loading and higher portions of biodiesel in the tested fuel mixtures minimized the gaseous NO_2 emissions.

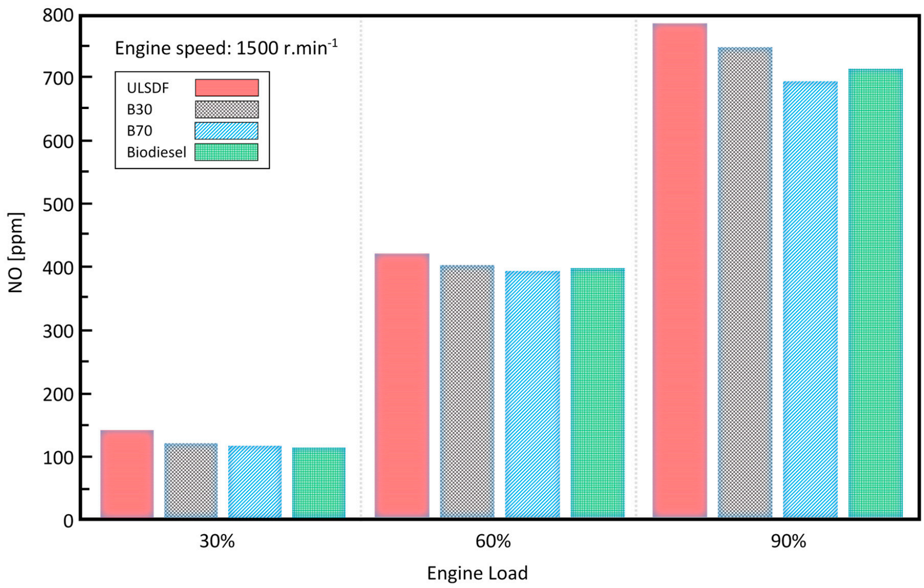

Figure 10. The dependence of testing fuels on the NO emissions (1500 rpm).

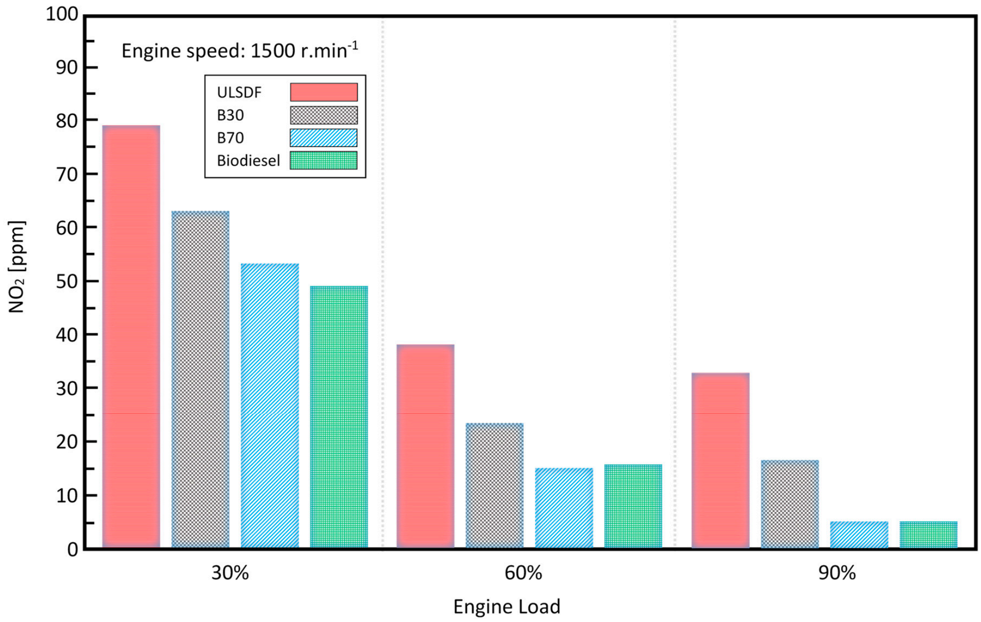

Figure 11. The dependence of testing fuels on the NO_2 emissions (1500 rpm).

4. Conclusions

The main task of this scientific-research work was to fill gaps within the current knowledge base concerning influence of bio-component fuels on production of the gaseous emissions. All the tests were performed using a 6-liter auxiliary diesel engine, which is usually installed in the marine ships. Various testing fuels were created by mixing of the biodiesel with the ULSDF. The applied mixing ratios were as follows: 0%, 30%, 70%, 100%, whereby the fuel mixtures were marked in the following order: B0: U100, B30: U70, B70: U30, B100: U0. Thus, the first tested fuel was the pure ULSDF (B0: U100) and the last tested fuel was the pure biodiesel (B100: U0). The individual experiments were performed using the engine speed values 1000 rpm or 1500 rpm and at the engine loading levels from interval between 30% and 90%. The obtained results can be summarized as follows:

- As the proportion of biodiesel in the experimental fuel increases, so the pressure of gas in the cylinder increases and intensity of heat release is significantly lower in this case.
- The ignition delay is shortened with increasing volume of biodiesel in the experimental fuel and at the same time the combustion process is faster. The ignition delay was on average about 2° longer.
- The NO_X emissions are higher if the engine speed and the engine loading levels increase. This fact is valid for every experimental fuel. On the other hand, a higher volume of biodiesel in the experimental fuel means a significant reduction of the NO_X emissions.
- The emissions of NO are higher if the engine loading level increases, but these emissions are decreasing with higher amount of biodiesel in the experimental fuel. The NO_2 emissions are significantly minimized if the engine loading level is increased and if amount of biodiesel in the experimental fuel is higher.

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