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INFLUENCE OF FUEL PROPERTIES ON ENGINE CHARACTERISTICS AND TRIBOLOGY PARAMETERS

Abstract

This paper deals with the mineral diesel, neat biodiesel and their blends and it discusses the influence of fuel properties on the engine characteristics with the aim to reduce harmful emissions. The considered engine is a bus diesel engine. The considered fuels are neat biodiesel from rapeseed oil and some of its blends with mineral diesel. The density, viscosity, surface tension, and sound velocity of tested fuels are determined experimentally and compared to those of mineral diesel. The obtained results are used to analyze the most important engine characteristics and tribology parameters.

Introduction

The key factors of diesel engine development are related to engine performance, economy, and ecology. In recent years many investigations have been done in order to reduce harmful diesel engine emissions. Some of the promising approaches are the precise control of the injection and combustion processes and the exhaust gas after-treatment technologies. In spite of respectful achievements, further reduction of engine emissions is still necessary since ecology regulations become every day more and more stringent. Furthermore, the independence of imported petroleum sources becomes ever more important. For this reason, over the past several years, the investigations on diesel engines have expanded in the area of alternative fuels, which are renewable, available locally, and cleaner than mineral diesel and may offer a way to reduce harmful emissions without worsening the engine power and fuel consumption drastically. With respect to harmful emissions, a very interesting alternative fuel is biodiesel.

Biodiesel offers advantages regarding the engine wear and availability [1][2]. Furthermore, it does not contain carcinogens, such as poly-aromatic hydrocarbons and nitrous poly-aromatic hydrocarbons. When burned, biodiesel produces pollutants that are less detrimental to human health [3]. On the other hand, high viscosity, high molecular weight, low volatility, etc. of biodiesel fuels may in some cases lead to problems such as severe engine deposits, injector cooking, and piston ring sticking [4]. These problems become evident at low fuel temperature, which causes the viscosity of biodiesel to increase beyond acceptable levels [5]. It is known that the kinematic viscosity is significantly influenced by compound structure, chain length, position, number, and nature of double bonds, as well as the nature of oxygenated moieties. Generally, the hydrocarbons in mineral diesel exhibit lower viscosity than the fatty esters comprising biodiesel. Furthermore, the contributions of fatty acid, oleate acid, linoleic acid, etc., depend on the biodiesel source, which can be derived from soybean oil, rapeseed oil, sunflower oil, olive oil, corn oil, etc. The contents of these fatty acids influence the contribution of methyl esters in biodiesel. Therefore, viscosity and other physical and chemical properties differ not only between mineral diesel and biodiesel but also among biodiesel fuels from different sources [6] [7] [8] [9]. These differences in the fuel properties cause noticeable variations in ignition, combustion and emission characteristics. The actual results, however, vary significantly in dependence on the employed engine, engine operating regimes, and used fuel [10] [11] [12] [13] [14] [15].

This paper deals with the mineral diesel, neat biodiesel and their blends and it discusses the influence of fuel properties on the engine characteristics with the aim to reduce harmful emissions. The considered engine is a bus diesel engine with mechanically controlled direct diesel fuel injection and M combustion system. The considered fuels are neat biodiesel from rapeseed oil (B100) and some of its blends with mineral diesel (D2). At first, the density, viscosity, surface tension, and sound velocity of tested fuels are presented. Then the experimental set-up and procedures are shown briefly. Finally, the influence of fuel properties on injection characteristics, engine performance and some tribology characteristics are discussed.

Properties of tested fuels

The fuels under consideration are: (i) neat mineral diesel (D2), conforming to European standard EN 590, (ii) neat biodiesel, here denoted as B100, conforming to European standard EN 14214, and (iii) their blends BXX, where XX denotes vol % of biodiesel (e.g. B25 consists of 25 vol % of biodiesel and 75 vol % of mineral diesel). All tested fuels are without any additives for winter conditions. Some specifications of B100 produced by Pinus-Slovenia from rapeseed along with the corresponding EN 14214 standard requirement are given in Table 1. A comparison between some measured properties of D2 and B100 are given in Table 2. Some other fuel properties, such as the sound velocity, bulk modulus of elasticity, and density of single-phase (fuel) and two-phase (fuel-vapor) fluid are determined experimentally in this work. The results are used to derive some empirical dependencies of these properties on temperature and pressure. Some measured properties of the D2 and B100 fuels are given in Table 2.

Fuel properties have a noticeable influence on engine characteristics. For this reason the most important properties of tested fuels have been determined experimentally.

Table 1: Biodiesel specifications

Fuel properties	Biodiesel - Pinus	European standard for Biodiesel, EN 14214
Cetane number	> 51	> 51
Ester content (% m/m)	96.9	> 96.5
Sulfur content (mg/kg)	< 10	< 10
Carbon residue on 10% distillation residue (% m/m)	< 0.3	< 0.3
Water content (mg/kg)	208	< 500
Oxidation stability, 110 ^{o}C (hours)	14.8	> 6
Acid value (mg of KOH/g)	0.24	< 0.50
Iodine value (g of I_2/100 g)	117	< 120
Linolenic acid methyl ester (% m/m)	8.5	< 12
Methanol content (% m/m)	0.01	< 0.20

Table 2: Diesel and biodiesel properties

Fuel	D2	B100
Kinematic viscosity @ 30 ^{o}C (mm²/s)	3.34	5.51
Surface tension @ 30 ^{o}C (N/m)	0.0255	0.028
Calorific value (kJ/kg)	43.800	38.177
Cetane number	45-55	> 51

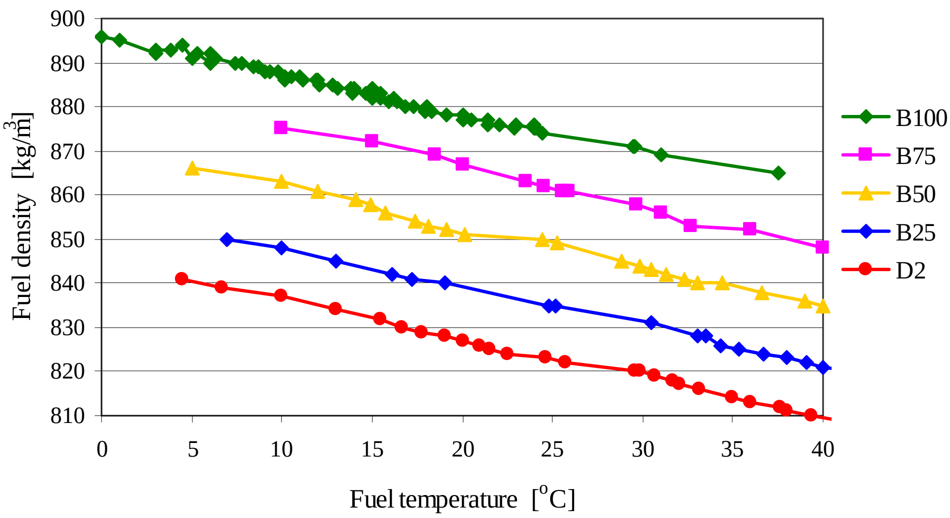


Figure 1: Fuel density with respect to temperature and biodiesel content

The fuel density is measured with Density meter DMA 35 PAAR. The fuel density, obtained by our experiment at ambient pressure, is presented in Figure 1. One can see that the density increases by increasing the content of B100 and by decreasing the fuel temperature.

The dynamic viscosity of fuels was measured with different fuels at two fuel temperatures, Figure 2. The results show that with lower fuel temperature the viscosity increases progressively with higher content of biodiesel in the fuel.

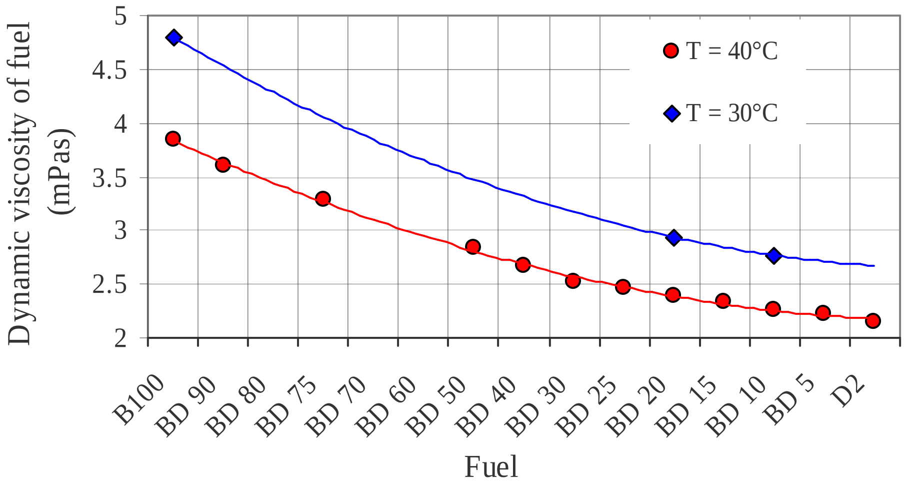


Figure 2: Fuels and fuel temperatures influences on dynamic viscosity

The surface tension of fuels was measured with various fuels at various fuel temperatures, Figure 3. The results show that with lower fuel temperature and with higher content of biodiesel in the fuel, the surface tension increases linearly.

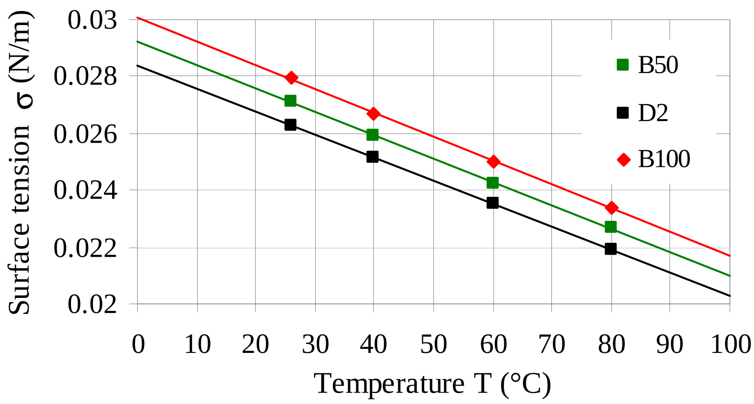


Figure 3:Fuels and fuel temperatures influences on surface tension

The measurement of sound velocity in fuel is based on the principle of pressure wave propagation in the high pressure (HP) tube, Figure 4.

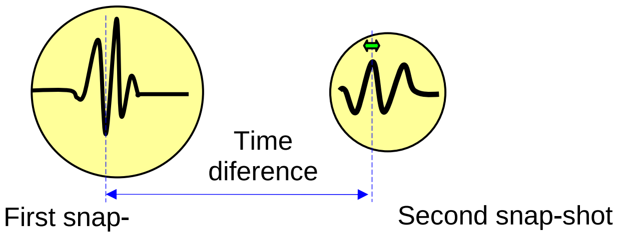


Figure 4: Principle of sound velocity measurement

The tube is instrumented by two piezoelectric pressure transducers, located at both ends of the tube. The sound velocity was measured at different pressures, up to 400 bar, using different fuels. Figure 5 shows the dependence of sound velocity at fuel temperature of 20 ^{o}C. One can see that by increased pressure and biodiesel content, the sound velocity also increases. A similar observation was made for the bulk modulus of all tested fuels.

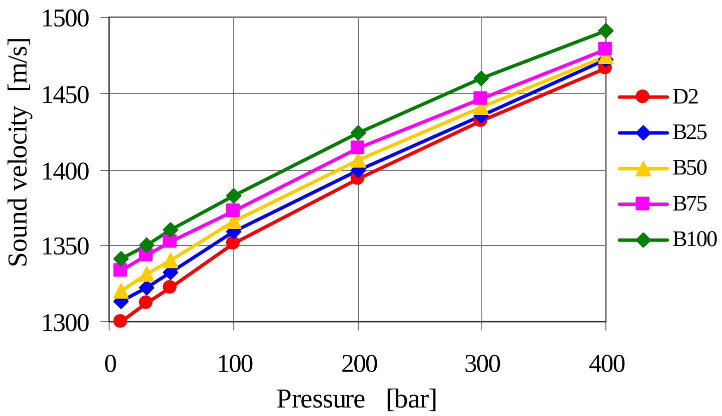


Figure 1: Sound velocity with respect to pressure and biodiesel content

One can see that the properties of tested fuels differ significantly. This means that biodiesel content will have a significantly influence on the combustion process and consequently on engine emissions and other tribology characteristics. For this reason some experiments have been carried out.

Experimental set-up and procedures

Two categories of analyses are presented, to study:

- the influence of fuel properties on engine characteristics at various engine operating conditions and
- the influence of fuel properties on tribology characteristics, especially on the surface roughness of pump plunger and nozzle needle after some period of biodiesel usage.

The engine characteristics have been tested with MAN bus diesel engine with direct fuel injection and M-mode combustion system. The main engine specifications are given in Table 3. The bus diesel engine overhauled after 500000 km travelling distance has been used in this experiment. Using a data acquisition system, instantaneous pressure in the fuel high pressure tube, instantaneous pressure in the cylinder, the temperatures of fuel, ambient air, intake air, cooling water in and out of engine, oil and the temperature exhaust gasses have been measured.

Table 3: Test engine and injection system main specifications

Engine model	MAN D 2566 MUM
Engine type	4 stroke, 6 cylinder in line, water cooled
Displacement	11 413 cm^3
Compression ratio	17.5 : 1
Bore and stroke	125 mm x 155 mm
Max Power	162 kW at 2200 rpm
Injection model	Direct injection and M combustion system
Fuel injection pump	Bosch PES 6A 95D 410 LS 2542
Pump plunger (diameter x lift)	9.5 mm x 8 mm
Fuel pipe (length x diameter)	1024 mm x 1.8 mm
Injection nozzle (number x nozzle hole diameter)	1 x 0.68 mm
Needle lift (maximum)	0.3 mm
Needle opening pressure	175 bar

The schematic diagram of the engine test bed is presented in Figure 6. The engine test bed consists of the Zöllner electro-dynamometer A-350AC, 300kW, the air flow rate meter RMG, the fuel consumption dynamic measuring system AVL, the UHC analyser Ratfisch, the NO_x chemoluminiscent analyzer Thermoelectron, the O_2 analyzer Programmelectronic, the CO analyzer Maihak, and the AVL smoke meter.

The tribology characteristics, especially the surface roughness of pump plunger and nozzle needle after some period of diesel and biodiesel usage are tested using device PERTHEN, which consists of the mechanical transducer RHT 3/6 and of the rotated head PURV 3-100. The surface roughness of pump plunger and nozzle needle are determined by two ways, in the circular and longitudinal directions, Fig. 7.

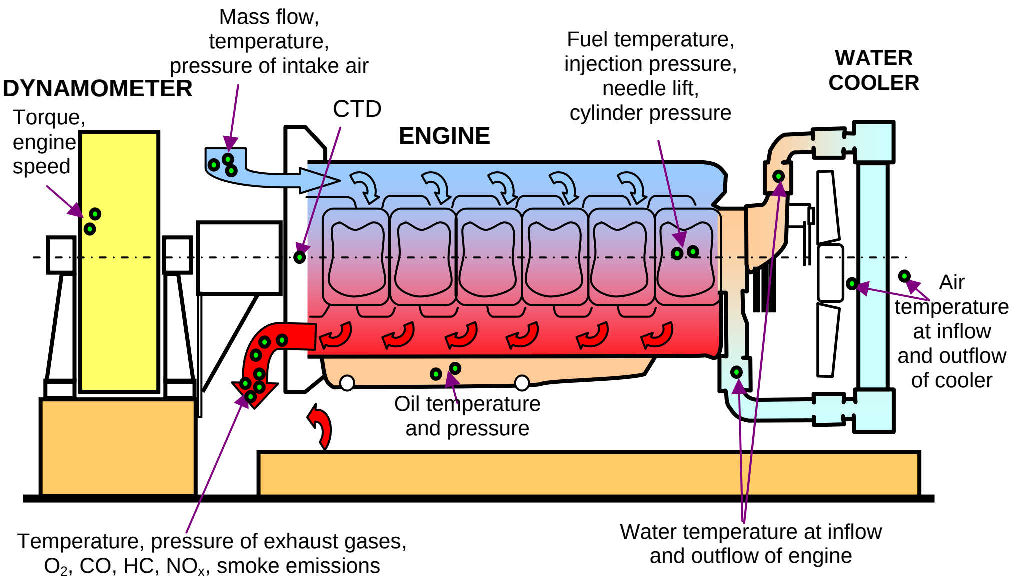
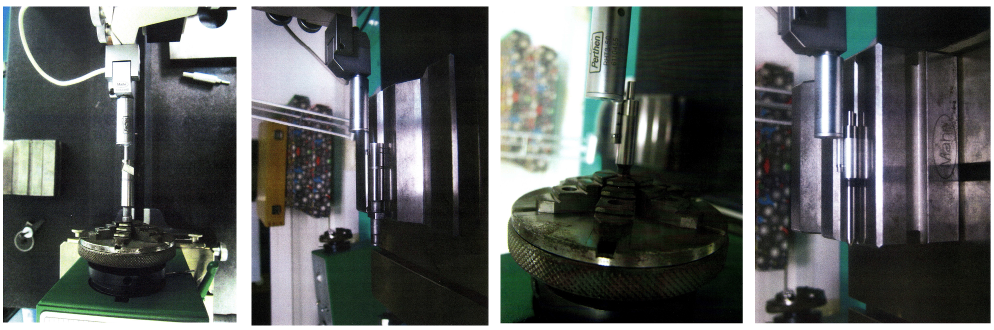


Figure 6:The engine test bed scheme

To determine the change of the pump plunger and the nozzle needle surface roughness due to diesel and biodiesel fuel usage, the following roughness parameters have been measured: the arithmetic roughness average R_a, the quadratic roughness average R_q, the maximum peak-to-valley height R_y, and the average peak-to-valley height R_z, are determined on the pump plunger and nozzle needle wall.



a) Pump plunger-circular b) Pump plunger-longitud c) Needle-circular d) Needle-longitudinal

Figure 7: The tribology measurements test bed

Fuel properties effect on engine characteristics

The experiments have been carried out with neat diesel D2, neat biodiesel B100 and their blends B25, B50, B75 at different operating regimes at fuel temperature of 20 °C, at constant pump injection timing and at the peak torque and the maximum power regimes. The experimental results are presented in Figure 8.

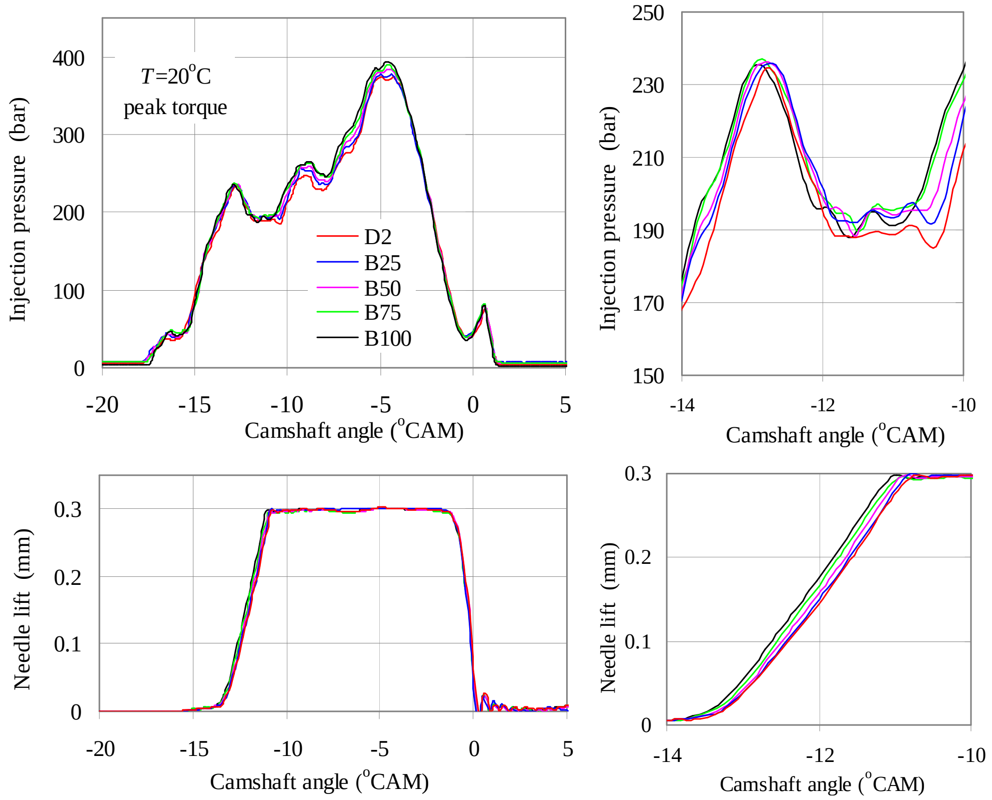


Figure 8: Fuel influence on injection pressure and needle lift at peak torque condition

This diagram shows that the maximum injection pressure increases with increasing biodiesel content and that the largest difference is about 40 bar. By increasing the pump speed at full load, the influence of biodiesel content is even more evident, Figure 9. The injection timing is advanced and the maximum of injection pressure increases by increasing the content of biodiesel.

The deviations in the viscosity and consequently in the bulk modulus, affecting the speed of sound, are responsible for the difference of injection timing, Figures 8,9. A higher bulk modulus, caused by increasing the content of biodiesel, leads to more rapid pressure wave propagation from the pump to the nozzle and an earlier needle lift. Higher viscosity of biodiesel leads to reduced fuel leakage during injection process, to faster pressure increase and thus to advanced injection timing.

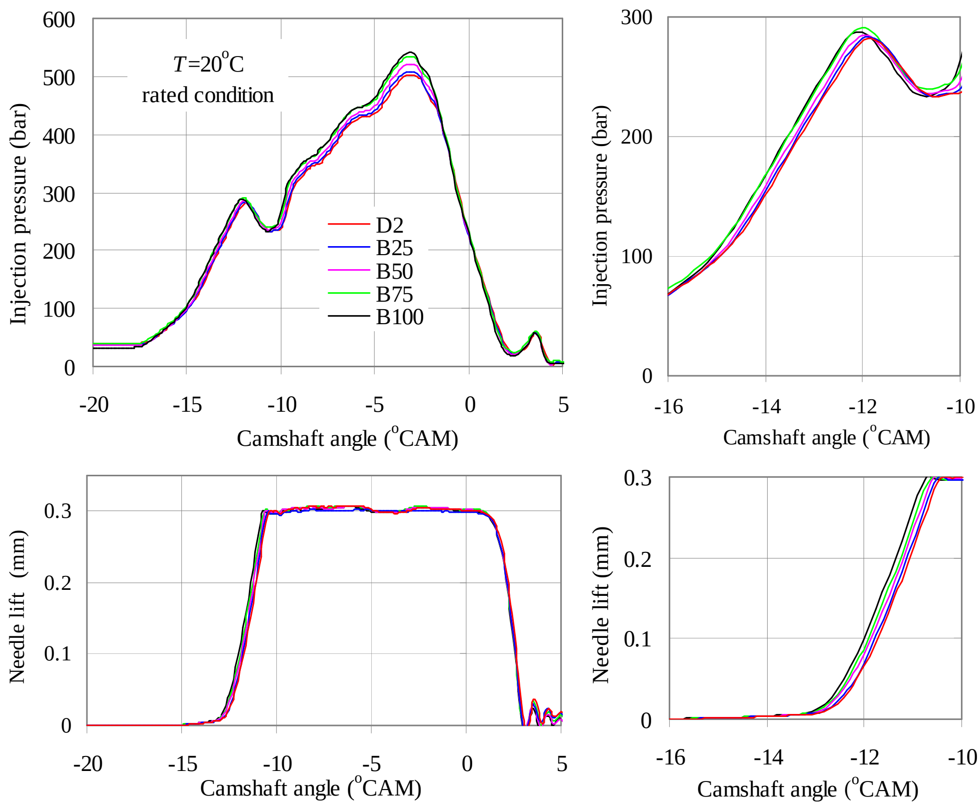


Figure 9: Fuel influence on injection pressure and needle lift at rated condition

Fuel properties, like density, viscosity, sound velocity, bulk modulus, cetane number, oxygen content and so on, have significant effects not only on the start of injection but also on the start of combustion and premixed and diffusion burn peak, influencing the emission and other engine performances. The influence of fuel on engine characteristics has been tested by running the engine with prescribed injection pump timing for D2 fuel. The comparison of some engine characteristics of D2 and B100 under full load conditions is shown on Figure 10. At full load the engine effective torque M_e and power P_e decreases by about 5% using B100 while the effective specific fuel consumption g_e (for the actual fuel mass) increases by about 10% in the whole engine speed regime. On the other hand, the temperatures of exhaust gases $T_{g,e}$ are lower by about 30°C, which may be due to the lower calorific value of B100.

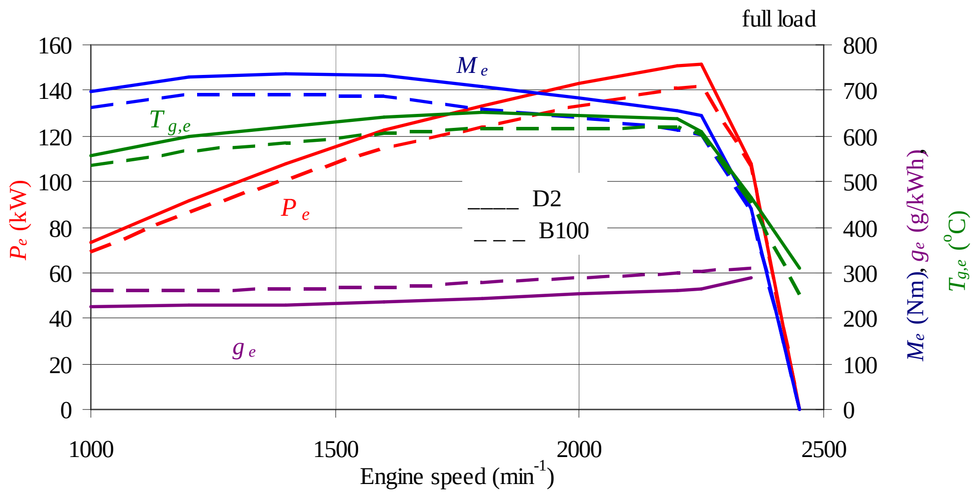


Figure 10: Influence of fuel on engine performance at full load conditions

By comparing the emissions of NO_x, smoke, CO and unburned HC, it is evident from Figure 11, that the NO_x emission increases at full in case the B100 fuel is used. An opposite effect is observed regarding smoke.

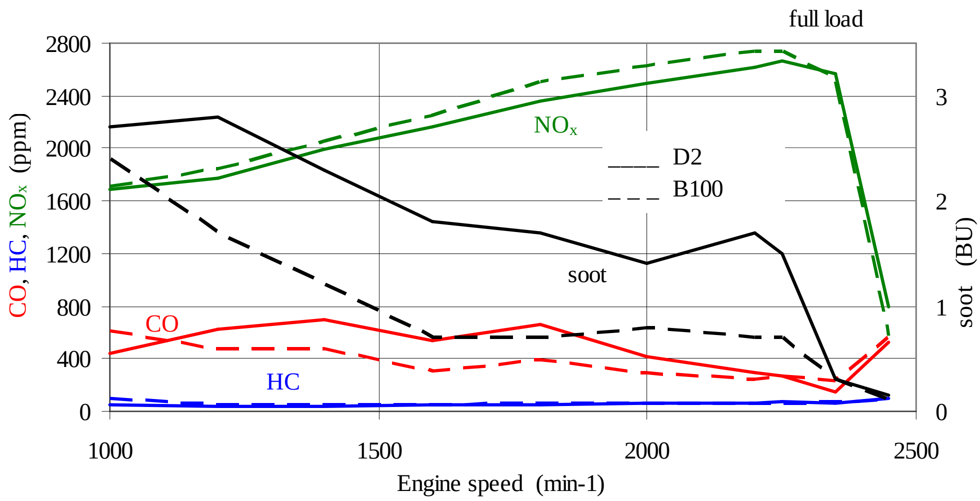


Figure 11: Influence of fuel on engine emissions at full load conditions

The CO and HC emissions are lower when using B100 almost at all engine speeds. The NO_x emission increases with higher engine speeds. This is primarily due to the increase of gas flow motion within the cylinder at higher engine speeds, which leads to a faster mixing of fuel and air, consequently to a shorter ignition delay causing higher pressure gradient and therefore higher gas temperature. Moreover, with increasing engine speed, the CO emission slightly decrease, meanwhile the HC emission is practically the same. The lower CO, HC and smoke emissions, when using B100 are likely primarily due to the fact that biodiesel contains more oxygen, which helps to oxidize these combustion products in the cylinder.

Fuel properties effect on tribology characteristics

In order to gain general information about the influence of diesel and biodiesel fuel on the pump plunger and nozzle needle wall surface roughness characteristics measured in longitudinal and circular direction, additional experiments have been carried out. At first, the surface roughness of new tested elements was determined. After 250 hours of running new elements with diesel and biodiesel at the same operating conditions, the surface roughness was measured again. As on example, the biodiesel influence on nozzle needle surface, measured in the circular direction, is presented on Figure 12.

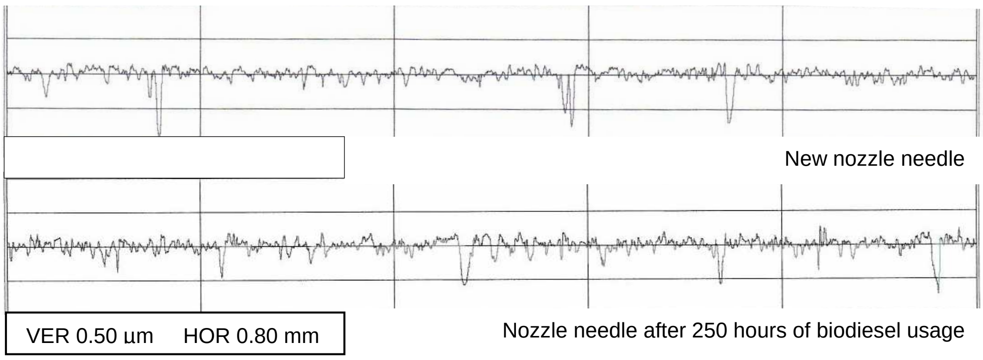


Figure 12: Influence of biodiesel on surface roughness on nozzle needle
(VER: 1 div/0,5 µm; HOR: 1 div/0,8 µm)

Diesel and biodiesel usage influences the surface roughness parameters at the pump plunger as well as on the nozzle needle wall, Figures13,14. However, the differences between biodiesel and diesel fuels influence are not obvious. One can see that all surface roughness parameters at the pump plunger wall, measured in the longitudinal direction, increased when biodiesel was used, while almost the opposite effect was obtained when diesel was used, Figure13. On the other hand, all surface roughness parameters decreased when biodiesel as well as diesel was used in all cases.

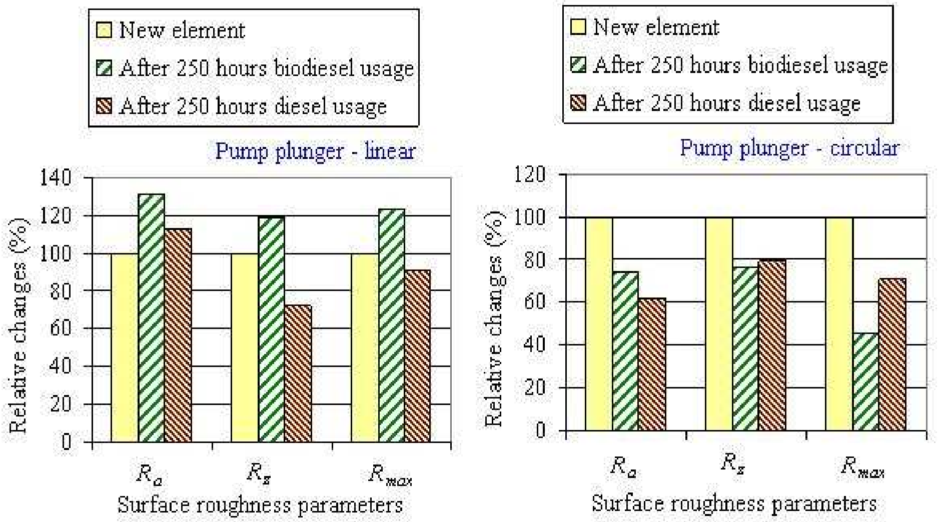


Figure 13: Influence of biodiesel on surface roughness on pump plunger

Similar results were obtained for the nozzle needle, measured in the longitudinal and circular directions, Figure 14.

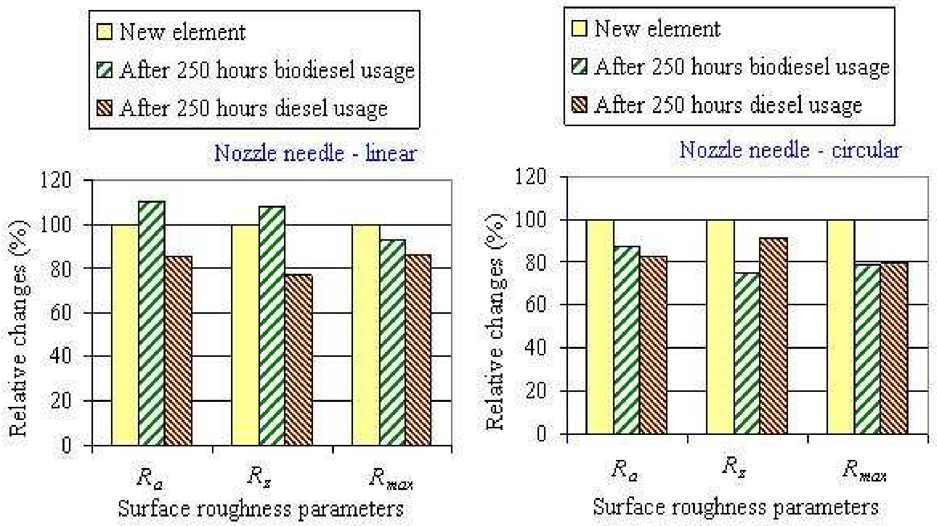


Figure 14: Influence of biodiesel on surface roughness on nozzle needle

To make an unique and explicit conclusion, longer test cycles and more experimental data are needed.

Conclusions

The paper presents the effects of biodiesel usage on engine performances and chosen tribology parameters of the bus diesel engine MAN D 2566 with mechanically controlled direct fuel injection and M combustion system. The used biodiesel has been produced from rapeseed oil. The properties of diesel, biodiesel and their blends are compared. The influence of fuels on engine characteristics is analyzed. Some attention is focused on tribology phenomena, especially the surface roughness of pump plunger and nozzle needle, as well. Based on the analysis of experimentally obtained results, the following conclusions can be made:

- By using the engine without any modifications, biodiesel has a positive effect on CO and smoke emissions and on exhaust gas temperature at full load conditions. The HC emission is increased at peak torque condition only. The specific fuel consumption increases. Regarding the smoke and NO_x emissions it can be concluded that B100 reduces smoke to a great extent, but increases the NO_x emission by about 5% at all tested regimes.
- The analysis of injection characteristics shows that the injection duration, injection timing, and injection pressure of higher content of biodiesel increase at rated and peak torque operating regimes. The higher sound velocity and bulk modulus of B100 lead to reduced injection delay and advanced injection timing.
- The use of biodiesel and diesel fuels for 250 hours has influenced the pump plunger and nozzle needle surface roughness. It seems that there are no significant differences between the influences of both fuels. However, some further tribology investigations would be necessary to evaluate this effect more precisely.

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UDK	ključne riječi	key words
621.436-634.5	biodizelsko gorivo	biodiesel fuel
544.16	ovisnost svojstava o kemijskoj strukturi	dependence of properties on chemical structure
621.891	tribologija (trenje, trošenje, podmazivanje)	tribology (friction, wear and lubrication)
539.375.6	trošenje klipa motora	engine piston wear

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