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Utilization of Biodiesel-Diesel-Ethanol Blends in CI Engine

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1. Introduction

The biodiesel's use can be considered as an alternative for compression ignition engines, but some of its properties (density, viscosity) present superior values compared with diesel fuel. These properties can be improved by adding bioethanol, witch on one side allows the content's increasing of the bio-fuel in mixture, and on the other side brings the reminded properties in the prescribed limits of the commercial diesel. First of all, the bioethanol is destined as an alternative for the spark ignition engines, but has applications for compression ignition engines, too.

The undertaken researches about partial replacement of the diesel fuel destined to diesel engines with mixtures biodiesel-diesel fuel-bioethanol (BDE), have as main purpose the identification and the testing of new alternative fuels for compression ignition engines, with similar properties of the commercial diesel fuel, having a high content of bio-fuel. In this case, it was started from the fact that by using BDE mixtures, some properties of the biodiesel and of the ethanol are mutually compensated, resulting mixtures with properties very similar with the ones of the diesel fuel. In the research, were used binary mixtures (BD, DE) and triple mixtures (BDE) between biodiesel (B) obtained from rapeseed oil, commercial diesel fuel (D) and bioethanol (E), in different proportions of these ones (the bio-fuel content varied from 5 % v/v to 30 % v/v, in scales of 5 % v/v, also for ethanol, and for biodiesel), having the purpose of evaluating the mixtures'(BDE) main properties and of comparing these ones with the diesel fuel.

The BDE mixtures were noted so the volumetric composition of the new fuels to be reflected. For example, the mixture B10D85E5 indicates the following volumetric composition of the component parts: 10 % biodiesel, 85 % commercial diesel fuel and 5 % ethanol.

At the established scale of researched fuels were taken into consideration the following criteria:

- the mixture's cetane number has not fall under the minimum value of the diesel fuel and of the biodiesel (51);
- the mixture's density has not be smaller than the one of the diesel fuel and has not be bigger than the one of the biodiesel;
- the mixture's caloric power has not fall with more than 5 % than the diesel fuel's caloric power;
- the three component parts has to be miscible until 0 °C temperature, and the formed mixture has to be long-term stable (at list three months from the preparation);

- the bio-fuel content has to be minimum 5 % v/v and maximum 30 % v/v;
- the mixtures' viscosity has to be near of the commercial diesel fuel's one.

The objective of this research, was focused on fitting the biodiesel-diesel fuel-bioetanol blends to compression ignition engines. This obiective carried out by:

- evaluating the use of biodiesel (rapeseed oil methyl esters) as an additive in stabilizing ethanol in diesel blends;
- blends selecting based upon mixture solubility and stability;
- determining the key fuel properties of the blends such as density, viscosity, surface tension, lubricity, flash point and cold filter plugging point;
- second mixtures selection based on phisical and chemical properties;
- engine performance and emission characteristics evaluation in laboratory condition;
- vehicle performance evaluation on chassis dynamometer;
- road test performances of biodiesel-diesel fuel-bioethanol blend.

Based on the undertaken researches regarding the miscibility, the stability, the lubrication ability and the main physicochemical properties (chemical composition, density, kinematic viscosity, limited temperature of filterability, the ignition temperature and superficial tension), from 27 mixtures BD, DE and BDE were selected three fuels (B10D85E5, B15D80E5, B25D70E5), which have similar properties as the diesel fuel.

The fuels thus selected were used for making the tests regarding the evaluation of the performances and regarding the pollution made by a Diesel engine, compared with the diesel fuel use, thus: *tests on the experimental stand for testing the compression ignition engines*, through the determination of the fuel's specific consumption, through the determination of the engine's performance and through the determination of the pollution emissions (CO, CO_2, NO_x, HC, smoke), at different tasks of its; *tests on the inertial chassis dynamometer* through the determination of the passenger car's power and torque; *road tests* through the determination of some dynamic features (vehicle elasticity, overtaking and accelerations parameters) of the tested passenger car.

2. The main properties of the biodiesel-diesel fuel-ethanol mixture component parts

The solubility, stability and properties of biodiesel-diesel fuel-ethanol ternary mixtures were investigated using commercial diesel fuel, biodiesel produced from rapeseed oil and ethanol with purity of 99.3 %. For eight selected blends viscosity, density, surface tension, lubricity, flash point and cold filter plugging point were measured and compared with those of diesel fuel to evaluate their compatibility as compression-ignition engine fuels. Standard recommended test methods were used in EN 590 to determine density at 15 °C (EN ISO 12185), flash point (EN ISO 2719), lubricity (EN ISO 12156-1), cold filter plugging point (EN 116). Viscosity at 40 °C was determined using ASTM D7042-04 and for determining surface tension the stalagmometric method was used. The main properties of the biodiesel, diesel fuel and ethanol used (Barabás & Todoruţ, 2009; Barabás & Todoruţ, 2010; Barabás et al., 2010) are shown in Table 1.

3. The miscibility and stability of the biodiesel-diesel fuel-ethanol mixtures

During the preparation of the mixtures BD, DE and BDE, it was observed their aspect before and after the homogenization. The mixtures, preserved 30 hours long at 20 °C temperature,

Fuels / Properties	D100	B100	E100
Carbon content, % wt.	85.21	76.97	52.14
Hydrogen content, % wt.	14.79	12.24	13.13
Oxygen content, % wt.	0	10.79	34.73
Kinematic viscosity at 40 °C, mm^2/s	2.4853	5.5403	1.0697
Density at 15 °C, kg/m^3	843.3	887.4	794.85
Cetane number	52	55.5	8
Lower heating value, kJ/kg	42600	39760	26805
Flash point, °C	61	126	13
Lubricity WSD, μm	324	218	–
Surface tension at 20 °C, mN/m	29.0	38.60	19.19
Cold filter plugging point (CFPP), °C	-9	-14	–

Table 1. Main properties of the fuels (biodiesel, diesel fuel, ethanol)

were visually re-inspected (all the mixtures become homogeneous, transparent and clear), after that they were cooled at 0 °C. The experiment was repeated also for the -8 °C temperature (with one grade Celsius over the diesel fuel's cold filter plugging point - CFPP, which is the highest one).

Regarding the BDE mixtures' miscibility and stability it can be mentioned that these can be realized in different proportions, becoming homogeneous and clear after about 30 hours from the preparation. The mixtures' stability depends on their temperature, thus: at 20 °C temperature the mixture up to 15 % v/v bioethanol content remain stable; at 0 °C temperature the mixture up to 15 % v/v bioethanol content remain homogeneous (clear or diffuse), with the exception of the binary mixtures, which take place at the alcohol separation, found phenomenon also at the triple mixtures with a content over 15 % v/v bioethanol; at -8 °C temperature, the mixtures gain different aspects, thus: homogeneous and clear remain only the B30D70 and B25D70E5 mixtures; homogeneous, but diffuse become the B10D90, B5D95, D95E5 mixtures; clear with sediments (ice crystals) gain the B25D75, B20D80, B20D70E10, B20D75E5, B15D70E15, B15D75E10, B15D80E5 mixtures; separated in two levels (bioethanol + diesel fuel-biodiesel mixture) in case of the mixtures with an intermediate level of bio-fuel (B10D80E10, B10D85E5, B5D90E5) or in four levels (one level ethanol, followed by a paraffin emulsion level, diesel fuel-biodiesel mixture and emulsion formed by ice crystals and diesel fuel- biodiesel mixture) at the other mixtures.

The 27 types of studied mixtures comparative with diesel fuel have been realized respecting the presented compositions from figure 1. The results of these observations are shown in Figure 1 and are the first selection criteria of the blends. In the case of mixtures under the marking lines, the separation of the components was visible, while those located above remained stable (homogeneous).

4. The main properties of the selected biodiesel-diesel fuel-ethanol mixtures

4.1 Determining the key fuel properties of the investigated blends

After first selection of the blends we determined the mixtures key fuel properties under recommanded standard methods and calculus. In order to make the second selection, density, viscosity, surface tension, cold filter plugging point, lubricity, flash point, carbon

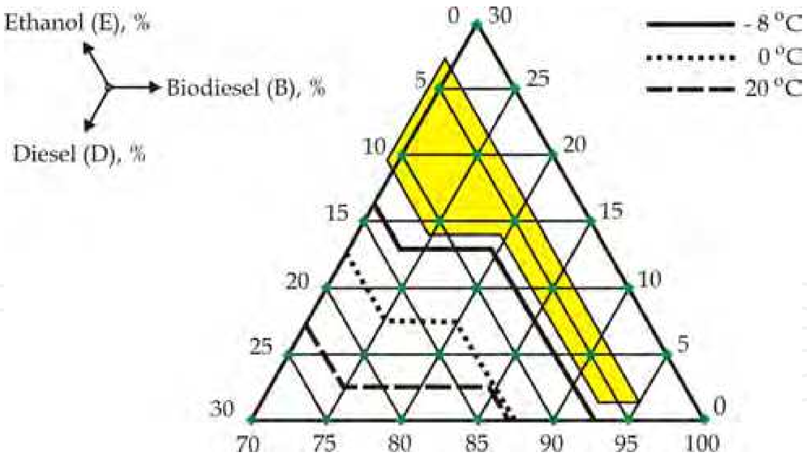


Fig. 1. Solubility and stability of biodesel-diesel fuel-ethanol blends

content, hydrogen content, oxygen content, cetane number and heating value of the blends was evaluated (measured or calculated) (Barabás & Todoruţ, 2009).

Density (ρ) is a fuel property which has direct effects on the engine performance characteristics (Sandu & Chiru, 2007). Many fuel properties such as cetane number and heating value are related to density. Fuel density influences the efficiency of fuel atomization and combustion characteristics (Sandu & Chiru, 2007). Because diesel fuel injection systems meter the fuel by volume, the change of the fuel density will influence the engine output power due to a different mass of injected fuel. Ethanol density is lower than diesel fuel density, but biodiesel density is higher.

Viscosity (ν) is one of the most important fuel properties. The viscosity has effects on the atomization quality, the size of fuel drop, the jet penetration and it influences the quality of combustion (Sandu & Chiru, 2007). Fuel viscosity has both an upper and a lower limit. It must be low enough to flow freely at its lowest operational temperature. Too low viscosity can cause leakage in the fuel system. High viscosity causes poor fuel atomization and incomplete combustion, increases the engine deposits, needs more energy to pump the fuel and causes more problems in cold weather because viscosity increases as the temperature decreases. Viscosity also affects injectors and fuel pump lubrication (Sandu & Chiru, 2007).

The surface tension (σ) of the fuel is an important parameter in the formation of droplets and fuel's combustion. A high surface tension makes the formation of droplets from the liquid fuel difficult.

The cold filter plugging point (CFPP) of a fuel is suitable for estimating the lowest temperature at which a fuel will give trouble-free flow in certain fuel systems. The CFPP is a climate-dependent requirement (between -20 °C and 5 °C for temperate climate).

Lubricity describes the ability of the fuel to reduce the friction between surfaces that are under load. This ability reduces the damage that can be caused by friction in fuel pumps and injectors. Lubricity is an important consideration when using low and ultra-low sulfur fuels. Fuel lubricity can be measured with High Frequency Reciprocating Rig (HFRR) test methods as described at ISO 12156-1. The maximum corrected wear scar diameter (WSD) for diesel fuels is 460 μm (EN 590). Reformulated diesel fuel has a lower lubricity and requires lubricity improving additives (which must be compatible with the fuel and with any additives already found in the fuel) to prevent excessive engine wear. The lubricity of biodiesel is good. Biodiesel may be used as a lubricity improver, especially unrefined biodiesel, while ethanol lubricity is very poor (Emőd et al., 2006; Zöldy et al., 2007; Rao et al., 2010).

The flash point (FP) is defined as the lowest temperature corrected to a barometric pressure of 101.3 kPa at which application of an ignition source causes the vapor above the sample to ignite under specified testing conditions. It gives an approximation of the temperature at which the vapor pressure reaches the lower flammable limit. The flash point does not affect the combustion directly; higher values make fuels safer with regard to storage, fuel handling and transportation (Rao et al., 2010). The flash point is higher than 120 °C for biodiesel (EN 14214), must be higher than 55 °C for diesel fuel (EN 590), and is below 16 °C for bioethanol.

The carbon content of the fuel determines the amount of CO_2 and CO in the burnt gas composition. Hydrogen content together with oxygen content determines the energy content of the fuel. Oxygen content contributes to the oxygen demand for combustion, providing more complete fuel combustion. The carbon, hydrogen and oxygen contents were calculated based on the composition of the constituents.

Cetane number (CN) is a measurement of the combustion quality of diesel fuel during compression ignition. It is a significant expression of diesel fuel quality among a number of other measurements that determine overall diesel fuel quality. The cetane number requirements depend on engine design, size, nature of speed and load variations, as well as starting and atmospheric conditions. Increase of cetane number over the values actually required does not materially improve engine performance. Accordingly, the cetane number specified should be as low as possible to ensure maximum fuel availability. Diesel fuels with a cetane number lower than minimum engine requirements can cause rough engine operation. They are more difficult to start, especially in cold weather or at high altitudes. They accelerate lube oil sludge formation. Many low cetane fuels increase engine deposits resulting in more smoke, increased exhaust emissions and greater engine wear. The cetane number was assessed based on the cetane numbers of the constituents and the mass composition of the blends (Bamgboye & Hansen, 2008).

The lower heating value (LHV) of the fuel determines the actual mechanical work produced by the internal combustion engine and the specific fuel consumption value. Since diesel engine fuel dosage is volumetric, the comparison of the volumetric lower heating value is more suitable. For this purpose it is useful to determine the *Fuel Energy Equivalence (FEE)*, which is the ratio of the heating value of the blend and the heating value of diesel fuel.

The main properties of the selected blends used (Barabás & Todoruţ, 2009; Barabás & Todoruţ, 2010; Barabás et al., 2010) are shown in Table 2. The densities of the biodiesel-diesel fuel-ethanol blends are in the range of 843.7...851.9 kg/m^3, very close to the diesel fuel requirement related in EN 590. In the case of the investigated blends kinematic viscosity is in the range of 2.3739…2.756 mm^2/s. The blends flash points that containing 5 % ethanol are in the range of 14…18 °C, and which containing 10 % ethanol are less than 16 °C. Measured values of surface tensions are in the range of 30.66…34.83 mN/m.

A significant decrease in the blends' flash point can be observed. The flash point of a biodiesel-diesel fuel-ethanol mixture is mainly dominated by ethanol. All of the blends containing ethanol were highly flammable with a flash point temperature that was below the ambient temperature, which constitutes a major disadvantage, especially concerning their transportation, depositing and distribution, which affects the shipping and storage classification of fuels and the precautions that should be taken in handling and transporting the fuels. As a result, the storage, handling and transportation of biodiesel-diesel fuel-ethanol mixtures must be managed in a special and proper way, in order to avoid an explosion.

Blends Properties	B5 D90 E5	B10 D85 E5	B15 D80 E5	B20 D75 E5	B25 D70 E5	B15 D75 E10	B20 D70 E10	EN 590
ρ, kg/m^3	843.7	845	847.2	849.6	851.9	844.7	846.8	820...845
ν, mm^2/s	2.4353	2.4205	2.5269	2.6447	2.756	2.3739	2.4796	2...4.5
FP, °C	17.5	14	16	17	18	15.5	16	55 (min.)
WSD, μm	305	232	276	243	252	272	264	460 (max.)
CFPP, °C	-18	-17	-13	-17	-16	-4	-7	climate-dependent
σ, mN/m	30.79	34.62	34.66	32.86	34.83	30.66	31.77	not specified
c, % wt.	83.22	82.79	82.37	81.94	81.52	80.80	80.38	not specified
h, % wt.	14.58	14.44	14.31	14.18	14.05	14.23	14.10	not specified
o, % wt.	2.20	2.76	3.32	3.88	4.43	4.96	5.52	not specified
CN	51.04	51.20	51.36	51.52	51.68	49.24	49.41	51 (min.)
LHV, kJ/kg	41707	41560	41414	41269	41124	40668	40524	not specified
LHV, kJ/L	35011	34979	34948	34916	34885	34219	34188	not specified
FEE	0.979	0.978	0.977	0.976	0.975	0.957	0.956	not specified

Table 2. Main properties of the blends

Concerning the cold filter plugging point (CFPP) it was observed that in the case of 5 % ethanol blends it decreases, but it gets higher in the case of 10 % ethanol blends because of the limited ethanol miscibility, which restricts its use at low temperatures (Barabás & Todoruţ, 2009).

Surface tension for blends containing 10 % ethanol is comparable to that of diesel fuel. Blends with high biodiesel content have a surface tension higher by up to 20 %, due to the higher surface tension of biodiesel (Barabás & Todoruţ, 2009).

Mixtures' density variation depending on temperature is depicted in Figure 2. Density of investigated mixtures varies depending on the content of biodiesel and ethanol in diesel. Increasing biodiesel content increases mixture's density, while increasing ethanol content leads to decrease its density. Comparing density of (Barabás & Todoruţ, 2009; Barabás et al., 2010) investigated fuels at 15 °C can be seen in Figure 3. It can be observed that mixtures in which the relation biodiesel content/ethanol content is less than 2 are within the imposed limits for diesel density EN 590, in terms of density.

Mixtures' viscosity variation with temperature (Barabás & Todoruţ, 2009; Barabás et al., 2010) is depicted in Figure 4. It can be observed that the ethanol reduced viscosity compensates biodiesel higher viscosity, and biodiesel-diesel fuel-ethanol blends have a closer viscosity to diesel, especially at temperatures above 40 °C. From Figure 5 it can be noted that all studied mixtures correspond in terms of kinematic viscosity to diesel imposed quality requirements EN 590 (Barabás & Todoruţ, 2009).

Surface tension of mixtures was determined at a temperature of 20 °C by an stalagmometric method (non-standard). Based on obtained results (Fig. 6) can be said that most biodiesel-diesel fuel-ethanol mixtures have a close superficial tension to diesel, ethanol successfully offsetting surface tension of a biodiesel (Barabás & Todoruţ, 2009).

The *flash point* was determined for all investigated blends using a HFP 339 type Walter Herzog Flash Point Tester, according to Pensky Martens method. Because the ethanol flash

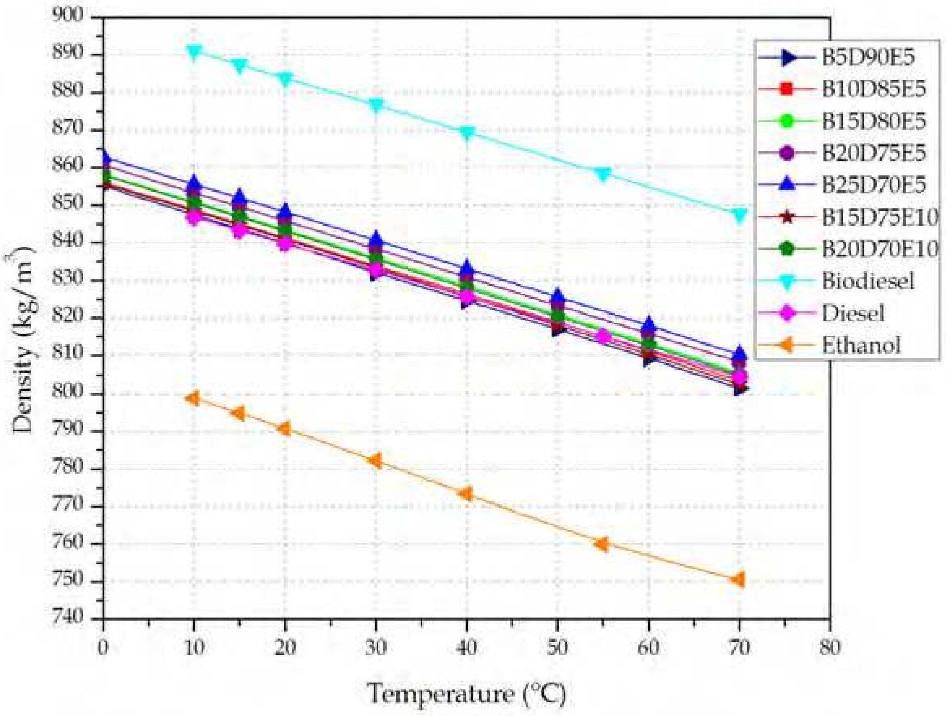


Fig. 2. Density variation with temperature

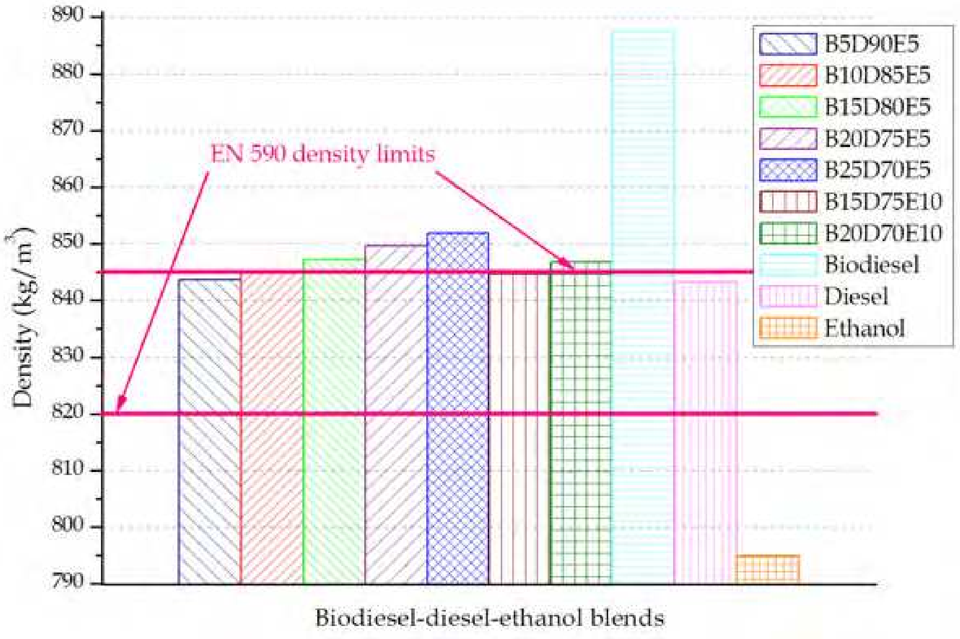


Fig. 3. Density of investigated fuels at 15 °C

point is very low, measured (Barabás & Todoruţ, 2009) flash points for biodiesel-diesel fuel-bioethanol blends are very close to bioethanol flash point (Fig. 7).

The investigated blends *cold filter plugging points* were measured (Barabás & Todoruţ, 2009) using an ISL FPP 5Gs type tester. CFPP is very different for each and also depends by solubility of biodiesel-diesel fuel-ethanol blends in test temperature (Fig. 8).

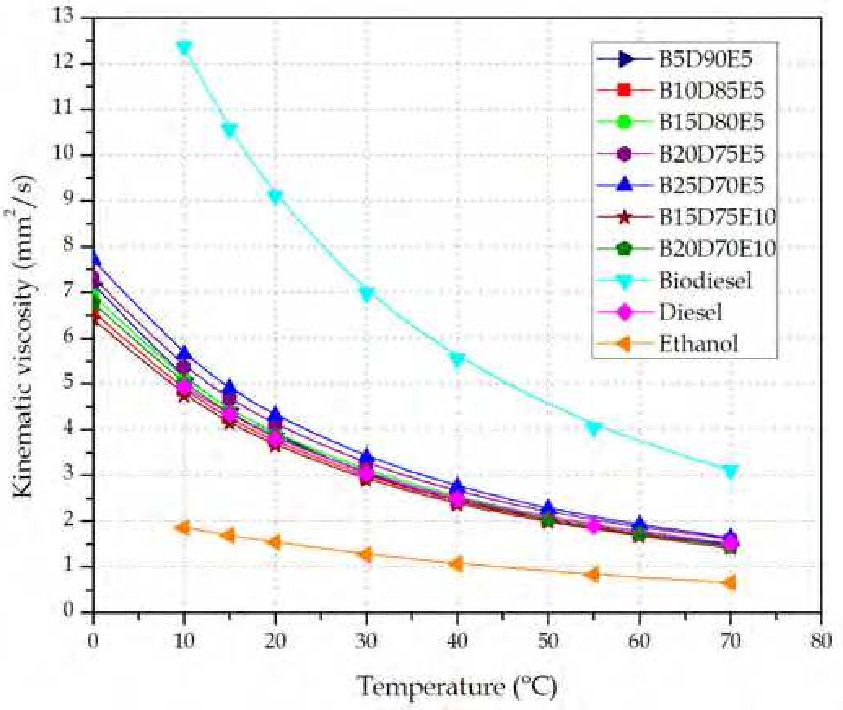


Fig. 4. Kinematic viscosity variation with temperature

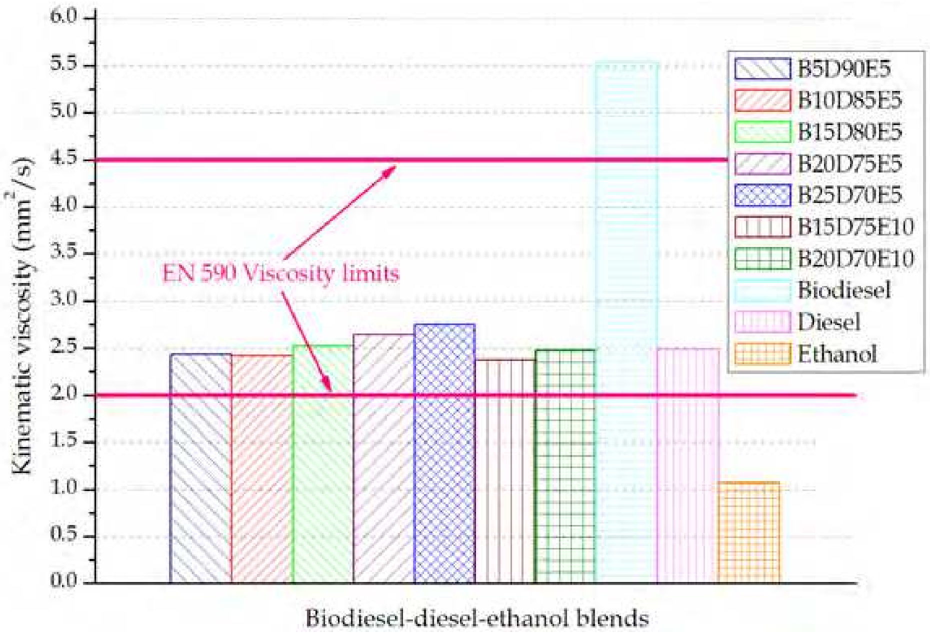


Fig. 5. Kinematic viscosity at 40 °C

4.2 Second mixtures selection based on phisical and chemical properties

For the second selection the following criteria were considered: volumetric lower heating value should not decrease with more than 3 %; cetane number should be over 51; density should not exceed the maximum limit imposed in EN 590 (845 kg/m^3) by more than 3 %, biofuel content should be above 7 % v/v (commercial diesel fuel may already contain max. 7 % v/v biodiesel) and various biodiesel/ethanol relations should be observed.

Based upon evaluated fuel properties (Table 2, Fig. 2 - Fig. 8), second mixtures selection was made. Selected blends was: B10D85E5, B15D80E5 and B25D70E5.

It can be seen that the biodiesel-diesel fuel-ethanol blends have a very close density to diesel fuel on the whole considered temperature domain.

There may be seen that the blends' viscosity is very close to that of diesel fuel, and the differences get smaller with temperature increase. Because the ethanol vaporizing temperature is quite small (approximately 78 °C), it will be in vapor state at the operating

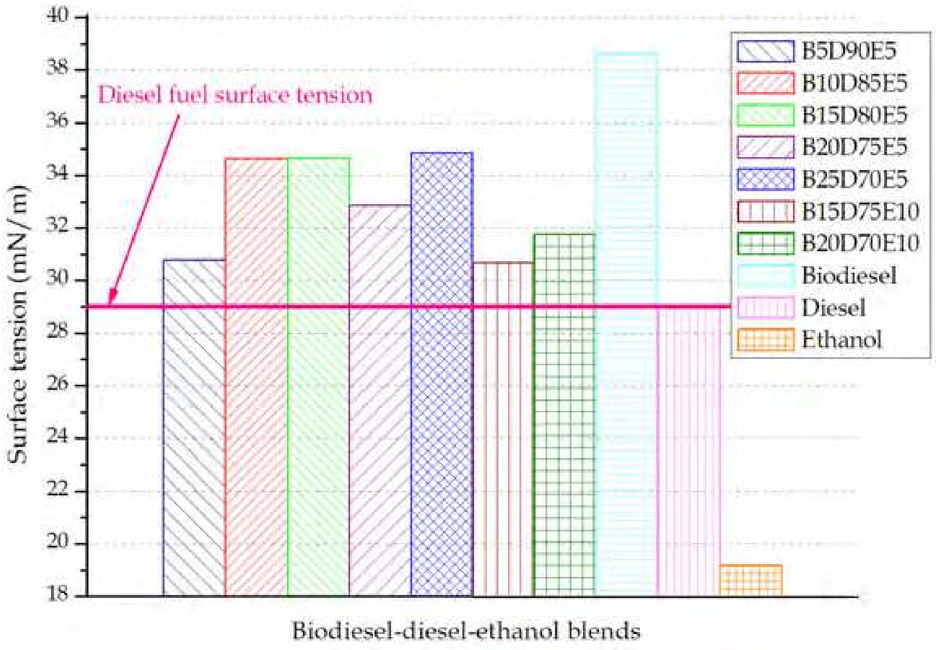


Fig. 6. Surface tension at 20 °C

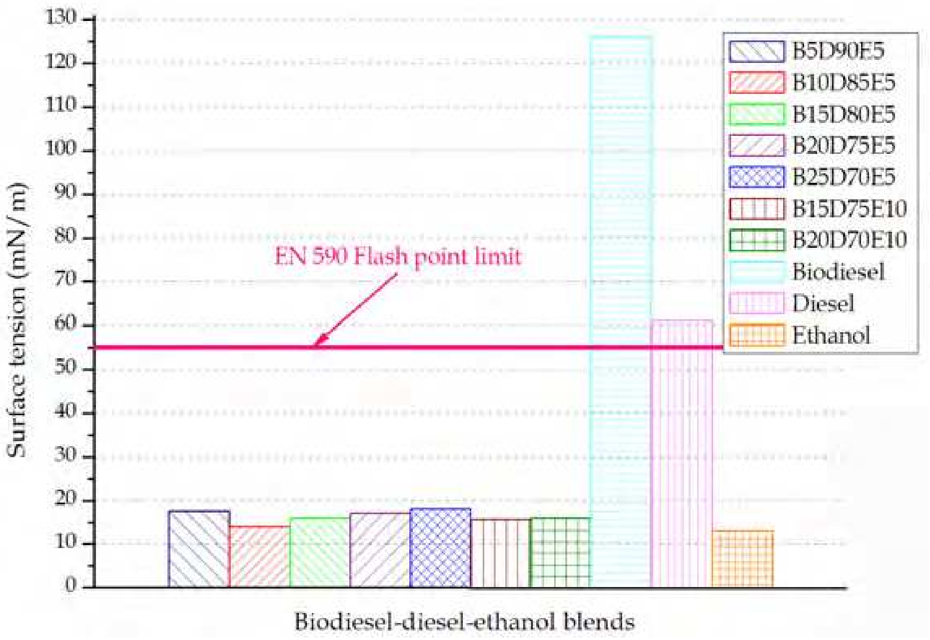


Fig. 7. Measured flash points for investigated biodiesel-diesel fuel-ethanol blends

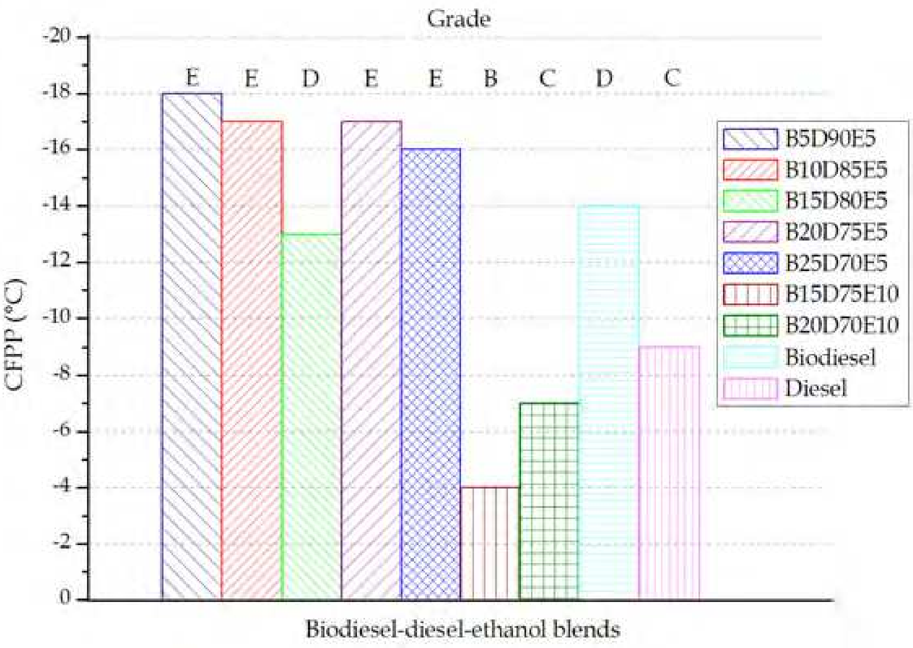


Fig. 8. Cold filter plugging point measured for different biodiesel-diesel fuel-ethanol blends

injector temperature. The compensation of biodiesel higher density and viscosity levels is important especially at low engine operating temperatures.

At the same time, a significant decrease in the blends flash point can be observed (14...18 °C) (Barabás et al., 2010). The flash point of a biodiesel-diesel fuel-ethanol mixture is mainly dominated by ethanol. All of the blends containing ethanol were highly flammable with a flash point temperature that was below the ambient temperature, which constitutes a major disadvantage, especially concerning their transportation, depositing and distribution, which affects the ship- ping and storage classification of fuels and the precautions that should be used in handling and transporting the fuel. As a result, the storage, handling and transportation of biodiesel-diesel fuel-ethanol mixtures must be managed in a special and proper way, in order to avoid an explosion.

Concerning the cold filter plugging point (CFPP) it was observed that in the case of 5 % ethanol blends it decreases (Barabás et al., 2010).

5. The performance and the emission evaluation features in the test bench

5.1 Engine performance and emission characteristics evaluation in laboratory condition

The experimental research concerning the ICE performances and pollution have been directed toward three fuel blends of biodiesel-diesel fuel-ethanol (B10D85E5, B15D80E5 and B25D70E5), for which diesel fuel has been used as reference. The experimental researches concerning the performances and the determination of pollutant emissions were developed on a test bench, equipped with a CI engine (number of cylinders - 4 in line; bore - 110 mm; stroke - 130 mm; compression ratio - 17:1; rated power - 46.5 kW at 1800 rpm; rated torque - 285 Nm at 1200 rpm; displacement volume - 4.76 l; nozzle opening pressure - 175 ± 5 bar; size of nozzle - 4 x 0.275 mm; injection system - direct, mechanical), hydraulic dynamometer and a data acquisition system for recording the operating parameters. For the evaluation of pollutant emissions the Bosch BEA 350 type gas analyzer was used (Barabás et al., 2010). The load characteristics have been drawn at 1400 rpm engine speed, this one being between the maximum torque speed and the maximum power speed. Before each test the fuel filters were replaced and the engine was brought to the nominal operating temperature. For evaluation, the obtained results were compared with those obtained in the case of diesel fuel. The results-evaluation has been made for three engine loading domains: small loads (0–40 %), medium loads (40–80 %) and high loads (>80 %).

Engine power and actual torque of the engine decreases with 5-9 % using the researched mixtures versus base diesel fuel. Also found that the engine speed corresponding to the maximal power decreases with 70-100 rpm when engine is fuelled with biodiesel-diesel fuel-ethanol blends.

Break specific fuel consumption (BSFC). The obtained results (Barabás et al., 2010) in the case of specific fuel consumption related to engine load are presented in Figure 9. The brake specific consumption is greater at smaller loads, but it decreases at medium and higher loads. The brake specific fuel consumption is greater for the blends, because their heating value is smaller. The sequence is D100, B10D85E5, B15D80E5 and B25D70E5 being the same at all engine loads, maintaining the increasing sequence of biofuels content. The increase is higher at small loads (32.4 % in the case of B25D70E5); at medium and high loads the determined values for blends are comparable with the values for diesel fuel, being between 6.2 % and 15.8 %.

Brake thermal efficiency (BTE). The engine efficiency variation with load for the studied fuels (Barabás et al., 2010) is shown in Figure 10. As it was expected, the engine efficiency decreases for fuel blends, the tendencies being similar with those of brake specific fuel consumption. The engine efficiency decrease is between 1.3 % and 21.7 %.

For *pollution evaluation* the emissions of CO, CO_2, NO_x, HC and smoke have been measured. The CO emissions (Fig. 11) vary according to the used fuel and according to the engine load (Barabás et al., 2010). Such as, at small and medium loads, the highest emissions were measured in the diesel fuel case, and the lowest ones in the B15D80E5 mixture case.

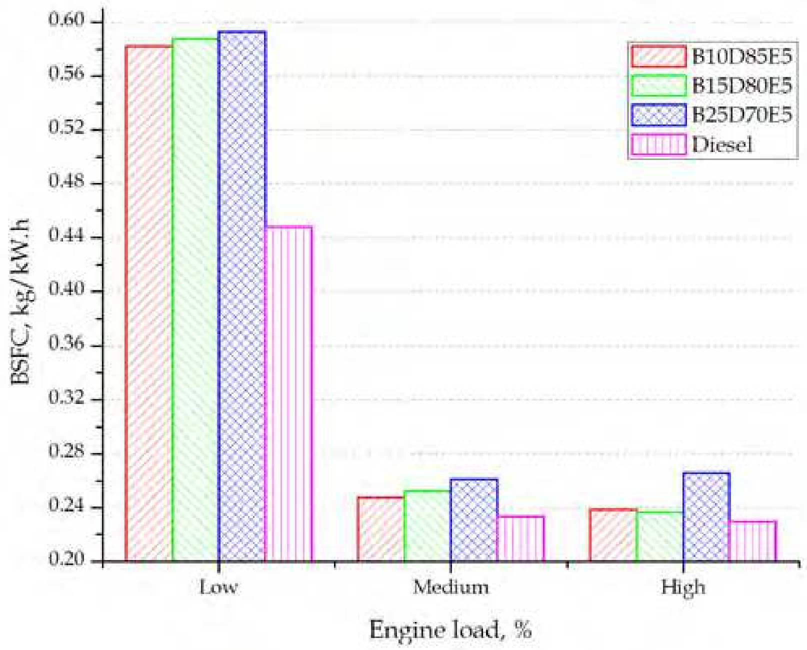


Fig. 9. Variation of brake specific fuel consumption of different fuels

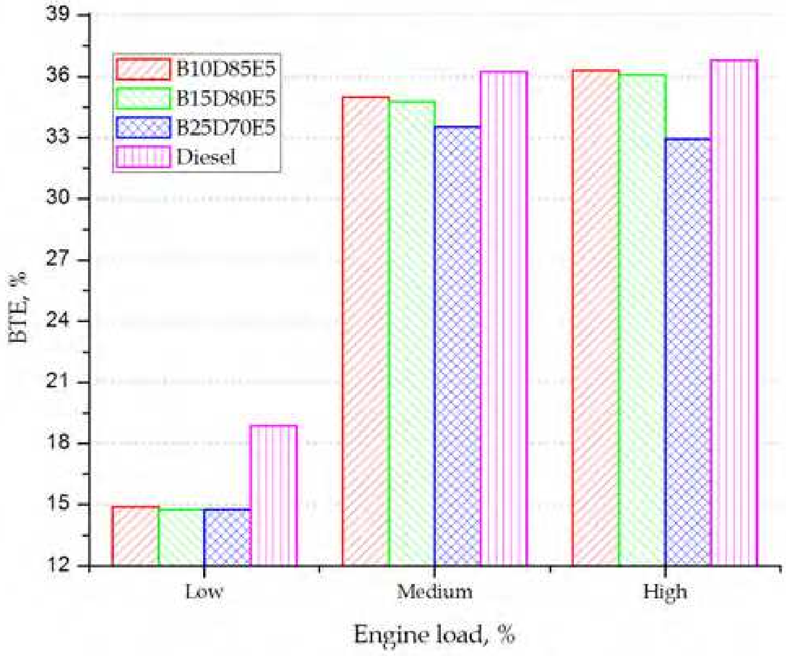


Fig. 10. Engine's efficiency variation with load for analyzed fuels

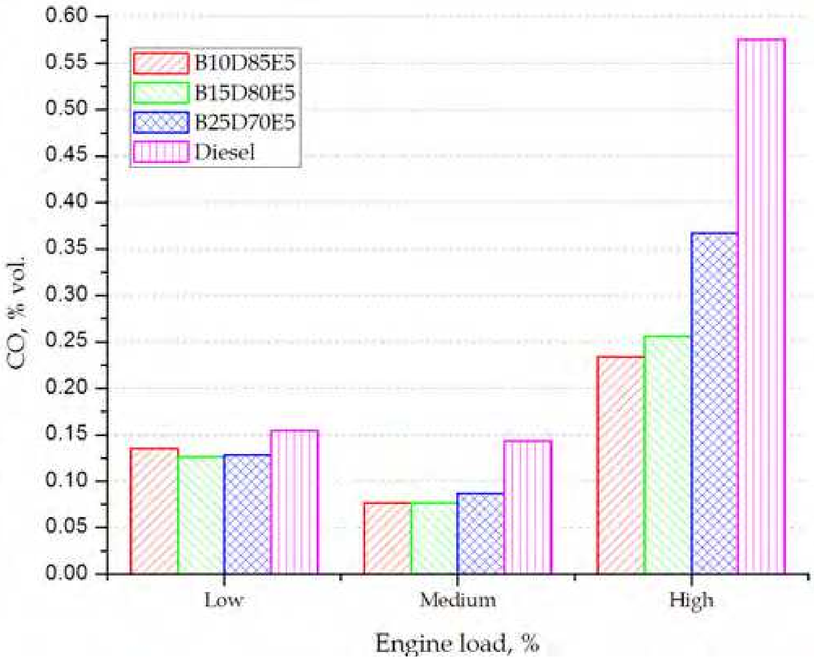


Fig. 11. Variation of CO emission with percentage of load for different fuels

As expected, at high loads increase the CO emissions, being lower in case of the researched mixtures with about 50 %. This fact is explained in (Subbaiah et al., 2010) by the high oxygen content of the biodiesel and of the ethanol witch sustained the oxidation process during the gas evacuation, too. The experimental results (Barabás et al., 2010) showed that at high engine loads, the lowest CO emission is for the B10D85E5 mixture (0.234 % vol.) which comparatively with the one seen in the diesel fuel case (0.575 % vol.) represents a 59 % reduction.

The CO_2 emissions (Fig. 12) in case of the researched mixtures are superior to those measured in case of the diesel engine function at all three regimes of loads taken into consideration (Barabás et al., 2010). The increasing level of the CO_2 emissions can be put on the decreasing CO emissions' account, which further oxidizes because of the high oxygen content of the researched mixtures providing a more complete combustion. Also, the oxygen excess made possible the CO oxidation during the evacuation process, too, including on the evacuation route of the combustion gas. This explication is also sustained by the decreasing of the CO emissions towards those seen in the diesel fuel case. The increasing of the CO_2 emissions cannot be considered as a negative consequence, because they are re-used (consumed) in the plants' photosynthesis process from which bio-fuels are fabricated.

Regarding the NO_x emissions (Fig. 13) of the Diesel engine tested with the researched fuels at different loads it was seen (Barabás et al., 2010) that the presence of the oxidized chemical component parts in the fuel at low loads has insignificant influence over the NO_x emissions levels, usually showing a slight reduction, but at medium and high loads the NO_x emissions are superior with 10-26 % to those seen in case of the diesel fuel. The increasing of the NO_x emissions at medium or high loads can be explained by the increasing of the fuel's combustion temperature, because of the oxygen content of biodiesel and ethanol, which made possible a more complete combustion and a increasing of the combustion temperature, which favors the formation of the NO_x. Also, because of the ethanol's reduced cetanic number, the mixture's cetanic number is reduced. This fact leads to the increased delay to ignition of the fuel, because of this the cumulated fuel/air mixture will burn more rapidly, creating a more rapid heat release at the beginning of the combustion process, resulting a higher temperature which favors the NO_x formation.

Regarding the HC emissions (Fig. 14) of the alternatively fueled engine with the researched BDE mixtures and diesel fuel, function by its load, it was seen (Barabás et al., 2010) that in case of the mixtures with 5 % ethanol content, the hydrocarbon emissions are reduced in significant way from diesel fuel in all three domains of the engine's load, the most significant reduction being seen in the high loads field about 50 %. The ethanol's presence in

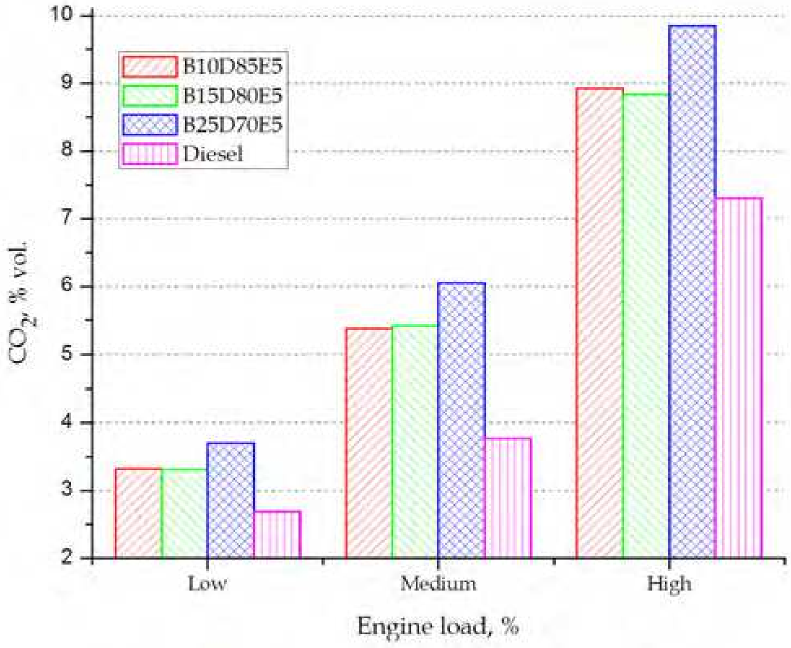


Fig. 12. Variation of CO_2 emission with percentage of load for different fuels

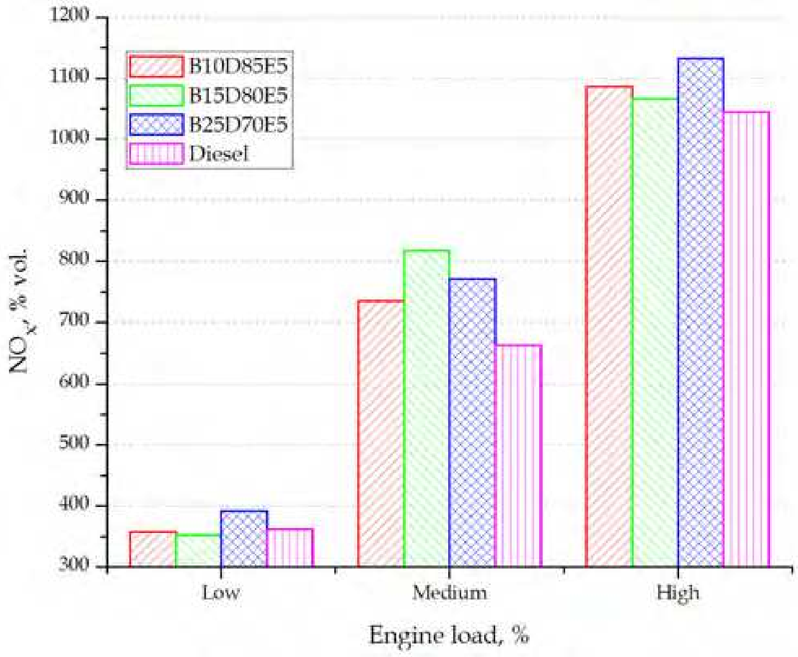


Fig. 13. Variation of NO$_x$ emission with percentage of load for different fuels

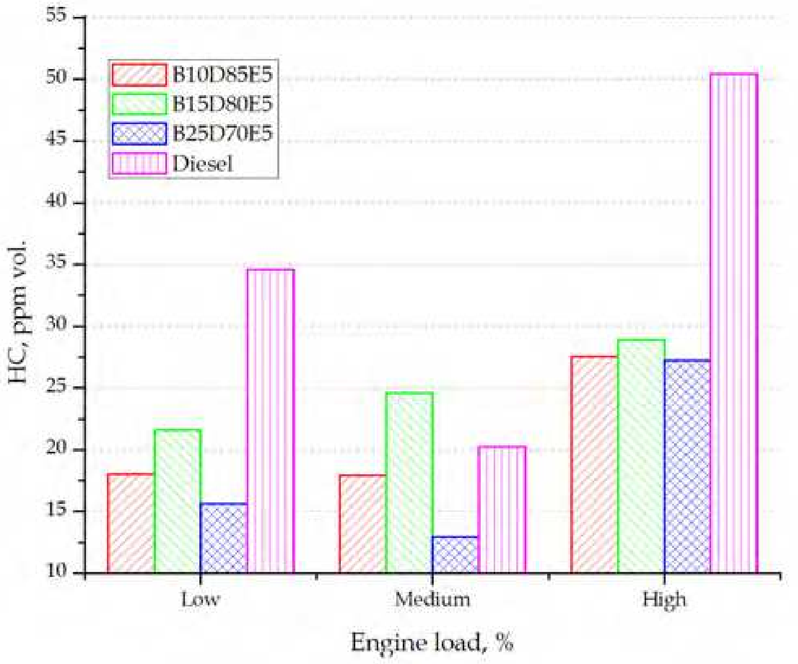


Fig. 14. Variation of HC emission with percentage of load for different fuels

mixture is an increasing factor of the HC emissions, while the biodiesel's presence leads to their reduction. An explanation it could be given through the cetanic number: the biodiesel having the cetanic number superior to the one of the diesel fuel favors easy ignition and a more complete combustion of the mixture, while the reduced cetanic number of the ethanol acts in opposite way. Because of the reduced cetanic number, the ethanol ignites later and it will burn incompletely, thus increasing the un-burnt hydrocarbons content from the evacuation gas composition.

The smoke emissions (Fig. 15) of the tested engine were evaluated by the measurement of the evacuation gas opacity, emphasized by the light's absorption coefficient (Barabás et al., 2010). The evacuation gas opacity it was significant reduced (with over 50 %) in case of the all mixtures, especially at low and medium loads. At high loads, the decreasing is between 27.6 % in the B25D70E5 mixture case and 50.3 % in the B10D85E5 mixture case. The smoke's formation takes place in the fuel reach fields of the combustion chamber, especially in the field of the injected jet's vein.

Concerning smoke opacity it has been observed that it decreases compared to the smoke opacity recorded in the case of diesel fuel, being higher for the fuel blends with high biofuel content.

Generally it may be concluded that the studied fuel blends have lower pollution levels, exceptions being CO_2 and NO_x, in which cases the recorded values are superior to those recorded for diesel fuel.

5.2 Vehicle performance evaluation on chassis dynamometer

For the comparative evaluation of the inquired fuel types, these were tested on a passenger car, equipped with a Diesel engine with a four strokes and six cylinders in line, with a maximum developed power of 86 kW at 4800 rpm and 220 Nm torque at 2400 rpm. To this end, tests for the evaluation of power and torque against engine speed were conducted on an inertial dynamometer, and road tests using GPS technology – to determine the dynamic characteristics of the test passenger car.

Tests on the dynamometer. On the dynamometer variation of power and torque measured at the wheel and engine power and torque were calculated for each fuel. Six tests were performed for each fuel and the average values of maximum power and maximum moment were calculated. The results obtained (Barabás & Todoruţ, 2010) are shown in Figure 16. When tested against diesel there was a reduction of maximum power with 3.6 % for the

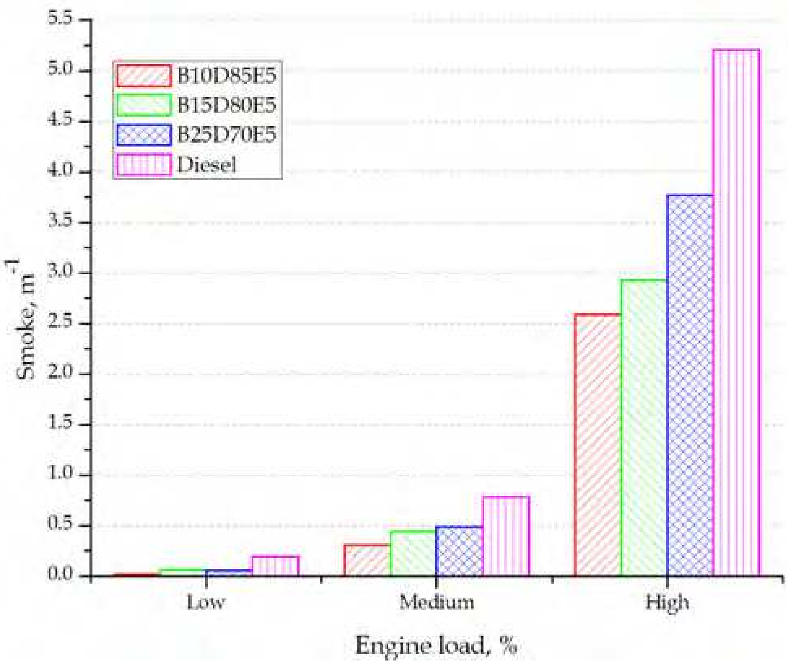
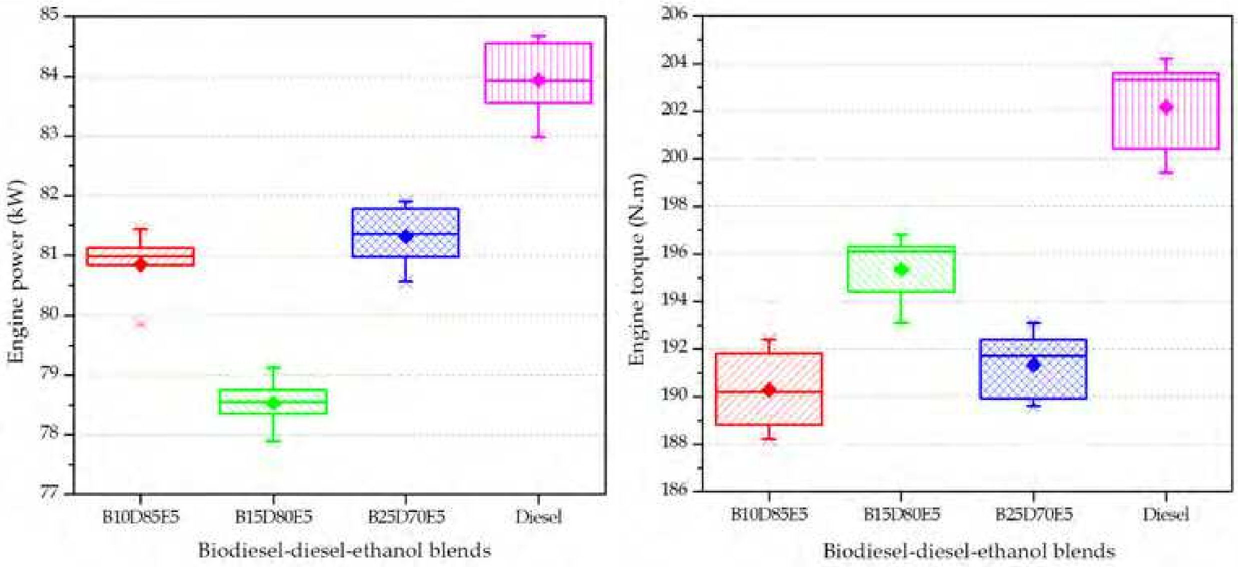


Fig. 15. Particle emissions



(a) (b)

Fig. 16. Maximum engine power (a) and torque (b) for selected fuels

B10D85E5 blend, with 6.4 % for the B15D80E5 blend and with 3.1 % for the B25D70E5 blend. Engine speed changes corresponding to maximum were observed, with 4750 rpm for diesel and 5050 rpm with B10D85E5 mixture and 5000 rpm for biodiesel, such a change wasn't detected with B15D80E5 mixture. Maximum engine torque also decreased using blends, when compared to diesel fuel: 5.8 % for the B10D85E5 blend, with 3.3 % for the B15D80E5 blend and 5.3 % when using the B25D70E5 blend.

5.3 Road test performances of biodiesel-diesel fuel-bioethanol blend

For road tests the following blends have been selected: B10D85E5, B15D80E5 and B25D70E5. The performed dynamic tests were intended to determine some of the passenger car's dynamic features like (Barabás & Todoruţ, 2010): vehicle elasticity, overtaking and accelerations parameters. The configuration of the vehicle and its attitude has been as determined by the manufacturer. The vehicle was clean, the windows and air entries were closed. The tire pressures were according to the specifications of the vehicle manufacturer. The mass of the vehicle has been its kerb mass plus 180 kg. Immediately before the test, the parts of transmission and tires were warmed up during a 30 km course. The measurements have been carried out on a 5 km long, straight, with hard, smooth, good adhesion track. Longitudinal slope was max. 0.5 % and transverse slope hasn't exceeded 3 %. The corrected value of air density during the test hasn't varied by more than 7.5 % from the air density in the reference conditions (temperature: 20 °C, pressure: 1000 mbar). The average wind speed measured at a height of 1 m above the ground was less than 3 m/s; gusts were less than 5 m/s.

Vehicle performance and speed test were evaluated over acceleration ability (acceleration 0-100 km/h and 0-400 m), elasticity in 4th gear - $t_{60\text{-}100\ \mathrm{km/h}}$, elasticity in 5th gear - $t_{80\text{-}120\ \mathrm{km/h}}$, overtaking in 3/4th gear - $t_{60\text{-}100\ \mathrm{km/h}}$, overtaking in 4/5th gear - $t_{80\text{-}120\ \mathrm{km/h}}$. To determine the elasticity and overtaking capability, 12 tests were conducted with each fuel, upon which the average values were calculated (Barabás & Todoruţ, 2010). The obtained road test results are shown in Figure 17.

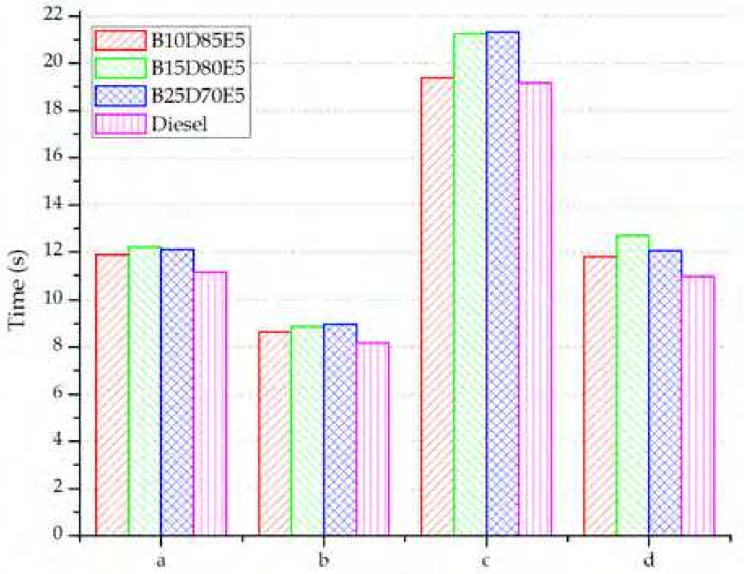


Fig. 17. Comparing dynamic parameters of the tested vehicle, when using mixtures, over the use of diesel-100 %: a - Elasticity in 4th Gear, $t_{60\text{-}100km/h}$; b - Overtaking in 3/4th Gear, $t_{60\text{-}100km/h}$; c - Elasticity in 5th Gear, $t_{80\text{-}120\ km/h}$; d - Overtaking in 4/5th Gear, $t_{80\text{-}120\ km/h}$

Fuel type / Characteristic	D100	B10D85E5	B15D80E5	B25D70E5
Acceleration (0-100 km/h), s	17.40	17.95	22.06	19.25
Acceleration (0-400 m), s	21.15	22.48	24.53	23.42

Table 3. The acceleration parameters results of the tested passenger car

It was found that the dynamic performances were reduced for all the blends studied, the weakest performance being obtained in case of the mixture B15D80E5. Performances obtained with blends B10D85E5 and B25D70E5 are comparable, but the latter has the advantage of a higher biofuel content.

When determining (Barabás & Todoruţ, 2010) the acceleration parameters, 6 tests were conducted and the best results were considered (Table 3).

6. Conclusion

This chapter presents the selection of biodiesel-diesel fuel-ethanol blends with a maximum biofuel content of 30 %, used to power compression ignition engines without their significant modification. It was found that among the original 27 mixtures only seven are suitable in terms of miscibility and stability, having an ethanol content of maximum 5 %. A comparison of the blends' main properties with those of diesel fuel has reduced the number of usable mixtures to three, having biodiesel content between 10 and 25 %.

The fuel blends used in the research for this paper have similar properties to those of commercial diesel fuel. The density of the blends is located near the maximum limit specified in EN 590. The kinematic viscosity values and the lubricity values are within the limits mentioned in the quality standard. Low flash point of mixtures requires special measures for handling and storage.

After the *performances of the Diesel engine evaluation*, by tests on the experimental stand for compression combustion engine testing, it was seen an increasing of *the specific fuel consumption* in the case of selected fuels (B10D85E5, B15D80E5, B25D70E5), on average with 15.85 %, respecting the ascending order of the bio-fuel content, and in case of the *engine's efficiency* it was seen a decrease around 10.36 % in case of the researched BDE mixtures used.

From the analysis of the obtained results regarding *the pollution produced by the tested engine,* charged with the new types of fuels, in which the diesel fuel was present, it is seen that the diesel fuel can be replaced with success by the BDE mixtures taken into the study, situations in which it is provided the noticed decreasing of the environmental chemical pollution (Table 4). The international targets regarding the gas decreasing which contribute to global environmental changes and to the improvement of the air quality at local level are satisfied by the bio-fuels properties compared with those of the classic fuels. The bio-fuels obtained by energetic plants are clean fuels, biodegradable and renewable, and their obtained technology is clean.

After the inertial chassis dynamometric tests, in case of BDE mixture use, it was seen a decreasing of the tested passenger car engine's power, on average with 4.41 % (Fig. 16.a), and of the torque engine with about 4.87 % (Fig. 16.b) in spite of diesel fuel use.

The road tests spotlighted a decreasing of the tested car performances, in case of all researched fuels compared with the diesel fuel use, presenting similar tendencies with those from the inertial chassis dynamometric tests. The comparison of the obtained results after road tests, regarding the elasticity and overtaking capability of the tested passenger car, spotlights the difference between the dynamic parameters obtained in case of the researched BDE mixture use, compared with the case of diesel fuel use, thus (Figure 17 and Table 3): elasticity in 4th gear, $t_{60\text{-}100\ km/h}$ - with about 8.23 %; overtaking in 3/4th gear, $t_{60\text{-}100\ km/h}$ - with about 7.88 %; elasticity in 5th gear, $t_{80\text{-}120\ km/h}$ - with about 7.84 %; overtaking in 4/5th gear, $t_{80\text{-}120\ km/h}$ - with about 11.25 %; acceleration 0-100 km/h - with about 13.52 %; acceleration 0-400 m - with about 11 %.

Engine loading domains and blends / Pollutant	small loads (0-40 %)			medium loads (40-80 %)			high loads (> 80 %)		
	B10 D85 E5	B15 D80 E5	B25 D70 E5	B10 D85 E5	B15 D80 E5	B25 D70 E5	B10 D85 E5	B15 D80 E5	B25 D70 E5
CO	–	– – –	– –	– – –	– – –	– –	– – –	– –	–
CO_2	+	+	+ +	+	+ +	+ + +	+ +	+	+ + +
NO_x	–	–	+	+	+ + +	+ +	+ +	+	+ + +
HC	– –	–	– – –	– –	–	– – –	– – –	– –	– – –
Smoke	– – –	–	– –	– – –	– –	–	– – –	– –	–

Table 4. The synthesis of the obtained results, compared with diesel fuel, regarding the emissions of the diesel engine's chemical pollutions tested with the researched fuels (B10D85E5, B15D80E5, B25D70E5)

In general, it was seen that from the point of view of the tested passenger car's performances, the BDE mixtures can successfully replace the diesel fuel.

It was found that in terms of performance, the B10D85E5 and B25D70E5 blends can successfully replace diesel fuel.

The researches regarding partial replacement of the diesel fuel destined to diesel engines with mixtures biodiesel-diesel fuel-bioethanol (BDE), can be continued through out the determination of the influences of research fuels on the research engine's technical condition (comparative evaluation of deposits on the engine parts; evaluation of engine parts wear; assessment of lubricating oil quality evolution).

7. Acknowledgment

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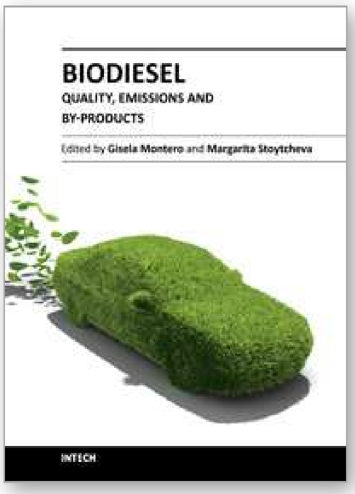

Biodiesel- Quality, Emissions and By-Products
Edited by Dr. Gisela Montero

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This book entitled "Biodiesel: Quality, Emissions and By-products" covers topics related to biodiesel quality, performance of combustion engines that use biodiesel and the emissions they generate. New routes to determinate biodiesel properties are proposed and the process how the raw material source, impurities and production practices can affect the quality of the biodiesel is analyzed. In relation to the utilization of biofuel, the performance of combustion engines fuelled by biodiesel and biodiesels blends are evaluated. The applications of glycerol, a byproduct of the biodiesel production process as a feedstock for biotechnological processes, and a key compound of the biorefinery of the future is also emphasized.

István Barabás and Ioan-Adrian Todoruț (2011). Utilization of Biodiesel-Diesel-Ethanol Blends in CI Engine, Biodiesel- Quality, Emissions and By-Products, Dr. Gisela Montero (Ed.), ISBN: 978-953-307-784-0, InTech, Available from: http://www.intechopen.com/books/biodiesel-quality-emissions-and-by-products/utilization-of-biodiesel-diesel-ethanol-blends-in-ci-engine

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