UNIVERSITY OF NIS FACULTY OF MECHANICAL ENGINEERING

THE TENTH INTERNATIONAL CONFERENCE
TRANSPORT AND LOGISTICS
https://doi.org/10.46793/TIL2025.149N

til 2025

INFLUENCE OF SELECTED BIODIESEL PROPERTIES ON FUEL CONSUMPTION

Boban Nikolić[1], **Breda Kegl**[2], **Jovan Dorić**[3], **Dragan Marinković**[4,5], **Nikola Petrović**[1]

[1)]Faculty of Mechanical Engineering, University of Niš, Serbia
[2)]Faculty of Mechanical Engineering, University of Maribor, Slovenia
[3)]Faculty of Technical Sciences, University of Novi Sad, Serbia
[4)]Department of Structural Analysis, Berlin Institute of Technology, Berlin, Germany
[5)]Institute of Mechanical Science, Vilnius Gediminas Technical University, Lithuania

ORCID iDs: Boban Nikolić https://orcid.org/0000-0002-9694-6719
Breda Kegl https://orcid.org/0000-0001-5139-0764
Jovan Dorić https://orcid.org/0000-0002-4532-4880
Dragan Marinković https://orcid.org/0000-0002-3583-9434
Nikola Petrović https://orcid.org/0009-0007-6093-3821

Abstract

The operation of diesel engines with biodiesel and its blends provides notable environmental and economic benefits. Although certain deviations in engine performance may occur, biodiesel remains a suitable alternative fuel when it meets regulatory standards. This study focuses on the difference in fuel consumption between biodiesel and diesel. Based on the analysis of a mechanically controlled fuel injection system, correlations between key fuel properties (density, speed of sound, and discharge coefficient) and fuel consumption were established, enabling the prediction of consumption differences depending on the physical and chemical characteristics of the fuel.

***Keywords**: biodiesel, density, viscosity, speed of sound, fuel consumption.*

1 INTRODUCTION

A systematic and comprehensive investigation of all processes influencing the transformation of the chemical energy of fuel into useful mechanical work is essential for the application of biodiesel and its blends with conventional diesel fuel in direct injection (DI) diesel engines. This includes a detailed analysis of the behavior within fuel delivery systems (pump, high-pressure lines, and injectors), as well as the characteristics and dynamics of the injection process (pressure, timing, duration, and end of injection, and spray formation). Furthermore, the mechanisms of fuel–air mixture formation and combustion must be thoroughly examined.

Particular attention should be given to the quantification of emission parameters (CO_2, NO_x, CO, HC, PM), both as a function of the chemical composition and visco–rheological properties of biodiesel and as a consequence of variations in injection and atomization regimes. In addition to the properties specified by relevant fuel standards, several physico-chemical parameters not covered by standards—such as the speed of sound, bulk modulus, surface tension, and compressibility—are of critical importance, since they directly affect pressure wave propagation, spray formation, and droplet size, and consequently influence mixture formation, combustion, and exhaust emissions.

Therefore, it is essential to investigate these non-standardized properties of biodiesel and their impact on injection performance, mixture formation, combustion process, fuel consumption, and exhaust emissions, in order to provide a reliable and applicable assessment of the suitability of such fuels for use in current and future diesel engines.

However, to obtain a comprehensive assessment of the suitability of biodiesel—and particularly of the feedstocks used for its production—for application in diesel engines, it is not sufficient to investigate only the influence of biodiesel on engine performance and exhaust emissions. A thorough understanding of the physico-chemical properties of biodiesel prior to its use as a fuel in diesel engines is essential. Numerous studies have demonstrated that the properties of biodiesel can vary significantly [1, 2]. Such variations depend on multiple factors, which can generally be categorized into two main groups: the feedstock base and the technological conversion process.

The choice of feedstock for biodiesel production is often determined by local and traditional cultivation of oil-bearing crops, as well as by climatic and soil conditions (typically in economically less developed countries), or by regulatory and legislative frameworks (common in more developed economies). Although the transesterification of vegetable oils into biodiesel represents a relatively simple chemical process, the technological procedures involved in biodiesel production have advanced considerably over the past two decades - particularly with the inclusion of various additives aimed at improving the physicochemical and operational properties of biodiesel.

Biodiesel produced from vegetable oil, used cooking oil, animal fat or fat residues from meat processing is treated as a renewable fuel. The key advantage of using biodiesel includes its significantly lower toxicity compared to diesel.

Studies comparing exhaust emissions from biodiesel and conventional diesel fuel generally indicate a reduction in exhaust smoke opacity, a significant decrease in carbon monoxide (CO) emissions, and a marked reduction in particulate matter (PM) formation.

However, with respect to nitrogen oxide (NO_x) emissions, the findings are highly inconsistent - some researchers report a decrease, while others observe an increase in NO_x levels. These discrepancies can be attributed to several factors, including differences in experimental setup (type of diesel engine, fuel injection system design, selection and properties of biodiesel used, and the presence or absence of an Emissions Control and Regulation System) as well as to the inherent nature of the HC-PM trade-off, which governs the complex relationship between hydrocarbon oxidation, soot formation, and NO_x generation during combustion.

The results concerning CO_2 emissions from diesel engines operating on biodiesel are inconsistent, varying with the type of biodiesel, engine configuration, and operating conditions. Both increases and decreases in CO_2 emissions have been reported. Considering that the combustion of biodiesel is generally more complete compared to conventional diesel fuel, a higher concentration of CO_2 in the exhaust gases can be expected—particularly since the concentration of CO tends to decrease because of more efficient oxidation processes during combustion.

In study [3], the authors reported similar findings: a reduction in CO emissions by 20–50%, HC by 30–70%, and PM by 40–70%, accompanied by an increase in NO_x emissions by 2–10% when operating with biodiesel blends ranging from B20 to B100 instead of conventional diesel fuel.According to [4], CO emissions decreased by 25–60%, HC by 30–80%, and PM by up to 60%, while NO_x emissions increased by 3–12%. A comparable trend was observed by the authors of the review paper [5], who reported a reduction in CO emissions by 30–50%, HC by 40–60%, PM by 40–70%, and an increase in NO_x emissions by 5–15%.

Based on a dataset comprising multiple agricultural and stationary diesel engines, the authors of [6] concluded that the average reductions in CO, HC, and PM emissions were approximately 42%, 57%, and 64%, respectively, while the average increase in NO_x emissions was around 7%.

When using biodiesel and its blends, a decrease in Brake Thermal Efficiency (BTE) was observed in the range of 1–4% for B20–B100 [3], 1–3% [4], and an average reduction of 1.8% according to [6]. An increase in Brake Specific Fuel Consumption (BSFC) of 2–8% was reported in [3], primarily due to the lower Lower Heating Value (LHV) of biodiesel, while [6] recorded a similar trend, with an average BSFC increase of approximately 4.5%.

The focus of this study is on the difference in fuel consumption of diesel engines when operating on biodiesel compared to conventional diesel fuel. By employing an analysis of the operation of a mechanically controlled fuel injection system [7], functional relationships were established that correlate selected fuel properties - such as density, speed of sound, and discharge coefficient - with the engine's fuel consumption. The goal is to enable, based on the physico-chemical characteristics of the fuel, a prediction of the expected difference in fuel consumption of a diesel engine operating with biodiesel or its blends, relative to operation with conventional diesel fuel.

2 SELECTED FEEDSTOCK INFLUENCES ON BIODIESEL PROPERTIES

Considering the diversity of feedstocks used for biodiesel production and the variety of technological conversion processes applied, our previous investigations [2] have demonstrated the wide range of values observed for several key biodiesel properties - such as density, kinematic viscosity, flash point, cetane number, iodine value, and oxidation stability.

This variability is particularly pronounced in the production of biodiesel derived from waste-based feedstocks, denoted in this study as WCO (waste cooking oil) or WFO (waste fish oil, chicken oil, pork fat, and other animal fats) [8].

Given the significant influence of these fuel properties on the operation of the fuel injection system (injection processes, spray formation, mixture preparation, and combustion) and consequently on the overall performance of diesel engines (output parameters, fuel consumption, emissions, etc.), this paper presents density profiles of various biodiesels (and their corresponding feedstocks, Fig. 1) and kinematic viscosity profiles (and related feedstocks, Fig. 2), depending on their origin and technological processing route.

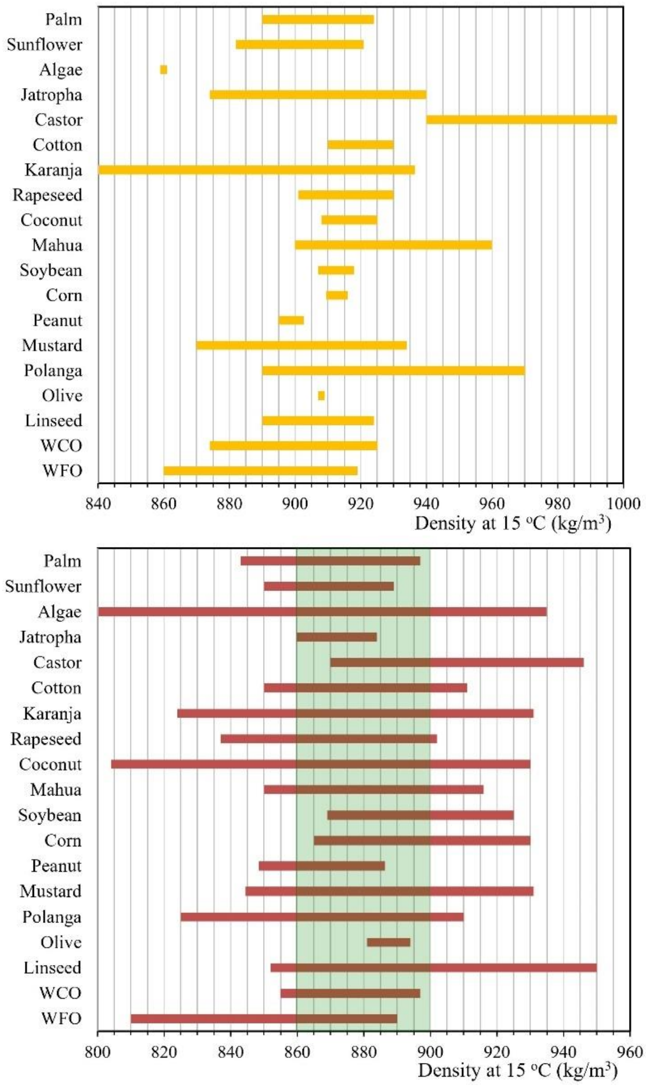

Fig. 1*Densities of biodiesel feedstocks (above) and corresponding biodiesels (below)*

The kinematic viscosity of biodiesel significantly influences the operation of the fuel delivery system, as well as the processes of fuel injection, spray formation, mixture preparation, and combustion, thereby affecting the emission characteristics of the engine. Fuel density is an equally important parameter with multiple implications. When considered from the standpoint of energy content per unit volume, a higher density would be desirable. However, fuels with density values above the specified limits may cause operational issues in the fuel delivery system and have a negative impact on injection dynamics, spray quality, and air–fuel mixture formation. Conversely, fuels with density values below the standard limits may also lead to malfunctions or irregularities in the fuel supply process. It should be noted that diesel engines are calibrated according to the properties of conventional diesel fuel, which serve as the reference fuel. Furthermore, fuel density is directly related to both the speed of pressure wave propagation (speed of sound) in the fuel delivery system and the fuel bulk modulus [7].

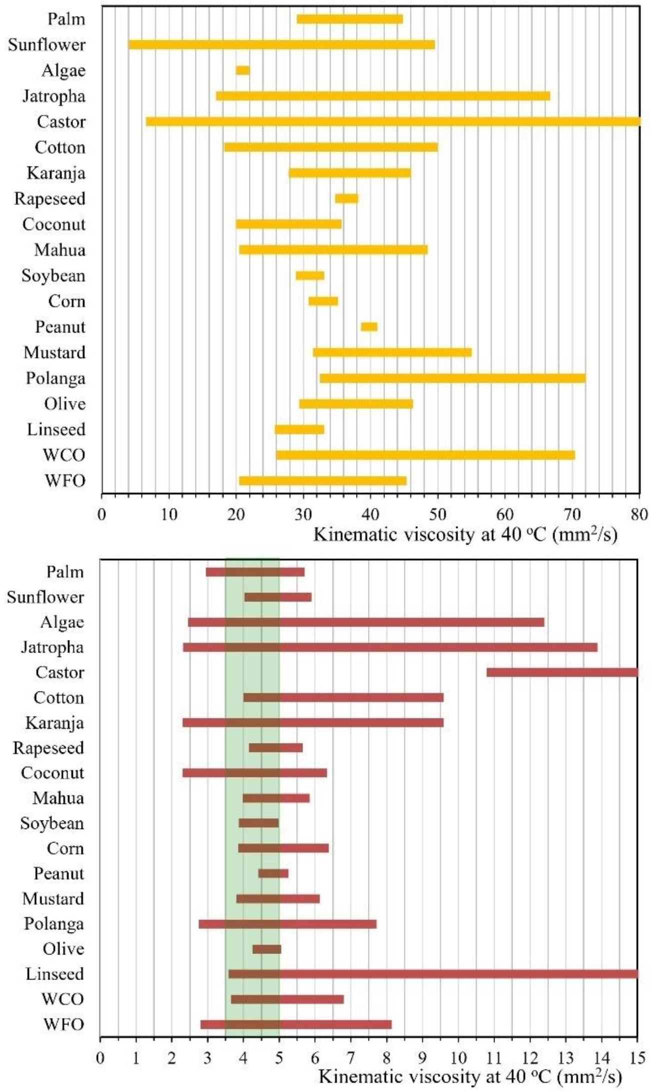

***Fig. 2** Kinematic viscosities of biodiesel feedstocks (above) and corresponding biodiesels (below)*

Analysis of the diagrams presented in Fig. 1 and 2 illustrates the extent to which biodiesel density and kinematic viscosity depend on the feedstocks used (including the applied processing technologies). These variations are not critical if the properties remain within the limits prescribed by the relevant biodiesel standards, such as EN 14214 in the EU and ASTM D6751 in the USA. In Fig. 1 (below), the green bar indicates the permissible range of biodiesel density according to EN 14214 (860–900 kg/m³), while in Fig. 2 (below), the green bar shows the permissible range of kinematic viscosity (3.5–5 mm²/s).

From the diagrams, it can be observed that even when biodiesel is produced from identical feedstocks, its physicochemical properties (here, density and kinematic viscosity) can deviate significantly from the values required by the standards. Particularly notable deviations in density are observed for biodiesels derived from algae, castor, karanja, coconut, polanga, linseed, and WFO. Likewise, large variations in kinematic viscosity are evident for biodiesels produced from algae, jatropha, cotton, karanja, polanga, linseed, WCO, and WFO. Such discrepancies highlight the complexity and variability of biodiesel production technologies, as well as possible inefficiencies during transesterification, purification, and quality control stages. At the same time, they reflect the inherent limitations in achieving uniform and standardized biodiesel properties when using different types or combinations of feedstocks. The kinematic viscosity values of castor biodiesel are notably above the upper EN 14214 limit, indicating the need for modification of such biodiesels - either by reducing their viscosity through process optimization, blending with other biodiesels, or by mixing with diesel fuel at lower concentrations. In practice, this is commonly applied: apart from neat biodiesel, blends of biodiesel and diesel fuel in various proportions are frequently used [2]; biodiesel may also be produced from mixtures of several vegetable oils [9] or as blends of different biodiesels [10, 11], with or without the addition of various performance-enhancing additives.

3 INFLUENCE OF BIODIESEL PROPERTIES ON FUEL CONSUMPTION

A schematic representation of the mechanically controlled fuel injection system in a diesel engine is shown in Fig. 3. The main components of the injection system include the High Pressure Pump (HPP), High Pressure Tube (HPT), and injector. A detailed analysis of the fuel flow within the HPT is presented in [7]. In this study, the fundamental assumptions and final expressions relevant to the subsequent analysis are provided.

Considering the compressibility of the fuel, the displaced fuel volume can be expressed as the sum of the injected fuel quantity and the residual fuel volume remaining in the system due to fuel compressibility:

$$v_p \cdot A_p = \mu_i \cdot A_i \cdot \sqrt{\frac{2}{\rho}} \cdot \sqrt{p_{II} - p_{cyl}} + \frac{dp_{II}}{dt} \cdot \frac{V_T}{E} \qquad (1)$$

where p_{cyl} denotes the pressure in the engine combustion chamber, and p_{II} represents the pressure upstream of the injector (Fig. 3, cross-section II–II).

Equation (1) does not account for the effects of inertia and reflection, nor for the deformation of the initial fuel flow caused by the motion of system components (the pump and injector) during the injection process. It is important to note that the fuel flow velocity is approximately 50–60 times lower than the speed of sound, while the displacement of the delivered fuel volume per cycle is about 10–15 cm. The newly delivered fuel from the pump pushes the fuel already present in the high-pressure line, while the pressure wave propagates at the speed of sound.

The injector does not respond instantaneously to the incoming signal but generates a return impulse, representing a reflection effect. Consequently, the instantaneous injection characteristics result from the combined influence of the pressure propagation and reflection waves. The movement of the injector needle changes the flow area, thereby altering the ratio between the injector flow cross-section and that of the high-pressure line, which directly affects the reflection conditions within the system.

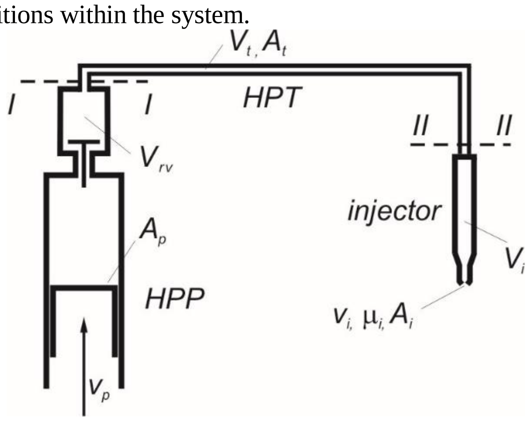

Fig. 3 *Injection system sheme: A_p, v_p - HPP piston face area and velocity, V_{rv} - relief valve casing volume, V_t, A_t - HPT volume and cross-section area, μ_i - discharge coefficient, $\mu_i A_i$- active cross-section of injector, v_i - fuel velocity from the injector, V_i - high-pressure volume part of the injector, V_T - total volume of the high-pressure system $V_T=V_p+V_t+V_i$*

The injected fuel quantity (injection rate), as a function of time (or camshaft/crankshaft angle), can be defined as:

$$\dot{V_i} = \mu_i \cdot A_i \cdot \sqrt{\frac{2}{\rho}} \cdot \sqrt{p_{II} - p_{cyl}} = \mu_i \cdot A_i \cdot v_i \qquad (2)$$

where v_i is the instantaneous velocity of fuel outflow from the injector nozzle. If the compressibility of the fuel within the high-pressure volume of the injector (V_i) is neglected - which is a reasonable assumption for modern injector designs where this volume is very small - the following relationship applies:

$$w_{II} \cdot A_t = \mu_i \cdot A_i \cdot v_i = \dot{V_i} \qquad (3)$$

That is, the fuel flow through cross-section II–II is equal to the injected fuel quantity. This relationship allows the determination of the injection rate by knowing the fuel velocity at cross-section II–II.

Based on Eq. (2) and (3), for the *k-th* fuel type (diesel, biodiesel, or blends) with density ρ_k the following expression is obtained:

$$w_{II} \cdot A_t \cdot \rho_k = \mu_{ik} \cdot A_i \cdot \rho_k \cdot \sqrt{\frac{2}{\rho_k}} \cdot \sqrt{(p_{II} - p_{cyl})_k} \qquad (4)$$

or equivalently:

$$\dot{G_k} = \mu_{ik} \cdot A_i \cdot \sqrt{2 \cdot \rho_k \cdot (p_{II} - p_{cyl})_k} \qquad (5)$$

where $\dot{G_k}$(kg/s) is the mass flow rate of the fuel.

Equation (5) relates the fuel consumption($\dot{G_k}$) to the characteristics of the injection system (A_i, p_{II}) and the fuel properties (μ_{ik}, ρ_k), considering that the effective flow area$\mu_{ik} \cdot A_i$represents a combination of the fuel's physical properties and the injector's geometric features. As such, it must be determined for each needle position (needle lift) of the injector. Additionally, differences in injection pressure p_{II}depending on the type of fuel should be considered. For the purposes of this analysis, average values ofμ_{ik}were adopted from the literature [12, 13, 14, 15] for the tested fuels.

For the same fuel injection system, when operating with diesel fuel, it can be expressed as:

$$\dot{G_D} = \mu_{iD} \cdot A_i \cdot \sqrt{2 \cdot \rho_D \cdot (p_{II} - p_{cyl})_D} \qquad (6)$$

and when operating with biodiesel:

$$\dot{G_{B100}} = \mu_{iB100} \cdot A_i \cdot \sqrt{2 \cdot \rho_{B100} \cdot (p_{II} - p_{cyl})_{B100}} \qquad (7)$$

From Eq. (6) and (7), it follows that:

$$\frac{\dot{G_{B100}}}{\dot{G_D}} = \frac{\mu_{iB100}}{\mu_{iD}} \cdot \sqrt{\frac{\rho_{B100}}{\rho_D} \cdot \frac{(p_{II}-p_{cyl})_{B100}}{(p_{II}-p_{cyl})_D}} \qquad (8)$$

In the following analysis, Eq. (8) was examined in two ways:
I) using the correlation function , and
II) using the measured pressure values.

The analysis of Eq. (8) using the relationship function between fuel flow velocity and pressure (K) is a simpler approach and relies on the findings from [7], where an equation was formulated that describes the correlation between fuel flow velocity and fuel pressure:

$$K = \frac{1}{a \cdot \rho} \qquad (9)$$

Additionally, the following approximations were introduced:

a) $\frac{\mu_{iB100}}{\mu_{iD}} \approx 1$, due to the similarity in the physical properties (density and kinematic viscosity) of biodiesel and diesel fuel, especially at higher injection pressures, and

b) $\frac{(p_{II} - p_{cyl})_{B100}}{(p_{II} - p_{cyl})_D} = \psi_p \cdot \frac{a_{B100}}{a_D}$ where ψ_p is a correction factor for the pressure difference, which can be determined by p_{II} and p_{cyl} measurements; for the present analysis, we will adopt $\psi_p \approx 1$.

In this way, Eq. (8) takes the following form:

$$\frac{\dot{G_{B100}}}{\dot{G_D}} = \sqrt{\frac{\rho_{B100}}{\rho_D} \cdot \frac{a_{B100}}{a_D}} = \sqrt{\frac{K_D}{K_{B100}}} \qquad (10)$$

In this way, by knowing the values of the parameters ρ and$a$for the tested fuels, the difference in injected fuel quantities can be predicted for diesel engines operating on biodiesel or biodiesel–diesel blends without additional experimental testing. In Chapter 4, the accuracy of this prediction will be evaluated.

For the analysis of Eq. (8) using the measured values of p_{II} andρ for the tested fuels (method II) and the values ofμ_i, we will assume that:

$$\frac{(p_{II} - p_{cyl})_{B100}}{(p_{II} - p_{cyl})_D} \approx \frac{p_{II\,B100}}{p_{II\,D}}$$

considering that the value of p_{II} is significantly higher thanp_{cyl}, particularly in high-pressure fuel injection systems. In this case, the following expression is obtained:

$$\frac{\dot{G_{B100}}}{\dot{G_D}} = \frac{\mu_{iB100}}{\mu_{iD}} \cdot \sqrt{\frac{\rho_{B100}}{\rho_D} \cdot \frac{(p_{II}-p_{cyl})_{B100}}{(p_{II}-p_{cyl})_D}} \qquad (11)$$

The discharge coefficient characterizes the efficiency of fuel flow through the injector nozzle relative to an ideal (theoretical) flow. When comparing diesel and biodiesel, typically differs due to variations in fuel properties such as density, viscosity, and surface tension.

According to [12], the discharge coefficient values for various biodiesel–diesel blends are approximately: B5: 0.77–0.81, B30: 0.58–0.78, and B100: 0.70–0.92 (estimated from figures). Authors [14] report discharge coefficient for diesel as 0.85–0.94, and slightly lower values for B100 as 0.80–0.90 (from reported data and figures). Similar trends are observed in [15], with μ_i for diesel: 0.80–0.94 and for B100: 0.70–0.90.
The general trend indicates that biodiesel exhibits a slightly lower discharge coefficient than diesel, typically 2–10% lower, depending on injection pressure, nozzle geometry, and fuel temperature.

4 EXPERIMENTAL SET-UP AND RESULTS

For the experimental investigation in this study, two high-pressure pumps (denoted as P1 and P2) and two injectors (denoted as B1 and B2) were used. The experimental fuels included conventional diesel (D) conforming to EN 590, rapeseed biodiesel (B100) conforming to EN 14214, and a 50% volumetric blend of biodiesel and diesel (B50). The injected fuel quantity was measured for all four combinations: P1B1, P1B2, P2B1, and P2B2. A description of the test rig and the specifications of measuring and components is provided in [7].
The characteristic values required for both methods of analyzing Eq. (8) from Chapter 3 (fuel cycling and injection pressures) are presented in Tables 1-4. Values are shown for different PVP speeds (400, 500, 600, 700, 800, 1000 i 1075/1100 min-1).

Table 1 Cycle fuel delivery (P1B1, P1B2) - exp. results

	P1B1 (mm^3)			P1B2 (mm^3)		
n(min^{-1})	D	B50	B100	D	B50	B100
400	172	174	179	133	134	136
500	176	180	183	132	134	137
600	174	179	182	135	138	140
700	176	183	187	140	142	144,5
800	180	186	192	140,5	142	144
1000	186	190	192	142	144	145
1100	185	188	190	139	142	144

Table 2 Cycle fuel delivery (P2B1, P2B2) - exp. results

	P2B1 (mm^3)			P2B2 (mm^3)		
n(min^{-1})	D	B50	B100	D	B50	B100
400	156	158	159	140	142	145
500	157	159	162	146	147	148
600	158	161	163	146,5	148	150
700	160	162	163	149	151	153
800	160	161	163	154	156	159
1000	157	158	159	157	159	161
1075	153	154	156	158	159,5	161,5

The diagram showing the variation of fuel density for the tested fuels as a function of pressure is shown in Fig. 4 [7]. The relationship function for the tested fuels is presented in Fig. 5 [7].
The measurement data expectedly indicate a slightly higher cycle fuel delivery when the injection system operates with biodiesel compared to diesel (Tables 1-2). Depending on the HPP–injector combination and the pump rotational speed (and consequently the injection pressure p_{II}), the differences range from approximately 1.3% to about 4%, and in an isolated case up to around 6% (P1B1: a non-optimized combination). For the optimized configurations (P2B1 and P1B2), the differences are between roughly 1.3% and 3.5%.

Table 3 Pressure p_{II} (P1B1, P1B2) - exp. results

	P1B1 (bar)			P1B2 (bar)		
n(min^{-1})	D	B50	B100	D	B50	B100
400	303	307	309	259	261	264
500	348	352	355	244	250	259
600	348	355	364	290	295	302
700	367	373	379	338	346	351
800	425	440	452	383	396	400
1000	505	529	550	443	466	485
1100	534	562	590	477	512	531

Table 4 Pressure p_{II} (P2B1, P2B2) - exp. results

	P2B1 (bar)			P2B2 (bar)		
n(min^{-1})	D	B50	B100	D	B50	B100
400	353	353	354	371	377	385
500	359	367	376	474	485	497
600	458	464	480	562	579	592
700	537	558	567	612	630	643
800	637	657	679	707	724	743
1000	759	795	830	851	876	896
1075	790	830	867	872	896	921

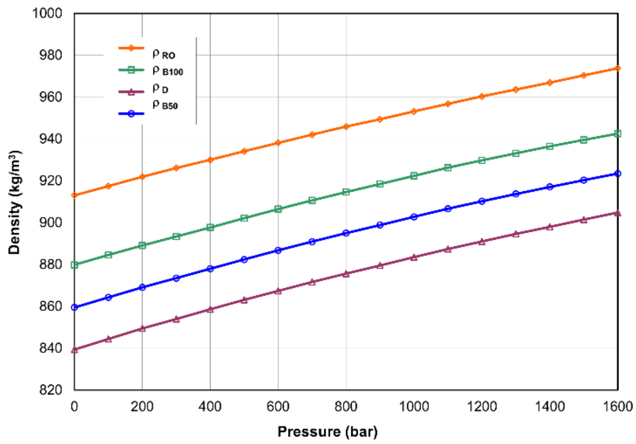

Fig. 4 *Density of tested fuels*

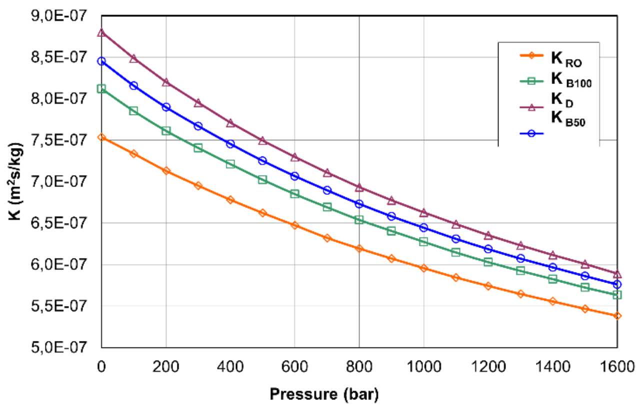

Fig. 5*Function K for tested fuels*

When B50 is used, the cycle-based fuel delivery values fall between those obtained for B100 and diesel, and the deviations relative to diesel are therefore roughly half of those observed for B100.

The injection pressure p_{II}values for biodiesel are up to approximately 10% higher than those for diesel fuel, depending on the PVP-injector combination and the pump rotational speed. The largest differences in p_{II} occur at the highest pump speeds, corresponding to the maximum injection pressure p_{IImax}. As expected, the values obtained with B50 lie between those measured for B100 and diesel fuel.

When the ratios of injected fuel quantities derived from experimental measurements are compared with the approximate values obtained using methods I and II (based on Eq. 8), the following trends are observed:

Method I indicates that the use of biodiesel leads to a moderate increase in fuel consumption, on the order of 3.7% to 2.7% across the injection-pressure range of 200–1000 bar, relative to diesel. The corresponding values for the B50 blend consistently fall between those of B100 and diesel, reflecting the expected intermediate behavior.

Method II predicts a somewhat broader range of deviation, with biodiesel yielding an increase in fuel consumption of approximately 1–5% within the same pressure range (200–1000 bar). Similar to method I, the B50 results remain intermediate, lying between the values observed for B100 and diesel fuel.

5 CONCLUSION

The conducted experimental and analytical investigation demonstrates that the physico-chemical properties of biodiesel - primarily density, speed of sound, and discharge coefficient - have a measurable and systematic influence on the operation of a mechanically controlled fuel injection system, and consequently on the fuel consumption of diesel engines.

Due to its higher density and higher speed of sound relative to conventional diesel fuel, biodiesel produces higher injection pressures p_{II}, with increases of up to approximately 10%, most prominently at the highest fuel pump speeds. This effect directly contributes to the observed increase in cycle fuel delivery. Across all pump–injector combinations, biodiesel consistently yields higher injected quantities than diesel, with experimentally measured differences typically ranging from 1.3% to 4% and reaching 6% in the non-optimized configuration P1B1. In optimized configurations (P2B1 and P1B2), the increase is lower, typically 1.3–3.5%. The B50 blend shows intermediate behavior, with deviations relative to diesel approximately half of those observed for B100.

A comparison of the experimentally measured cycle-based fuel delivery values (Tables 1-2) with the corresponding deviations calculated using Methods I and II shows that both methods reproduce the actual trends very well. For most operating regimes and all pump–injector combinations, the predictions from both methods deviate from the measured values by less than one percentage point, confirming that the selected set of physico-chemical parameters (density, speed of sound and discharge coefficient) adequately captures the key influences of biodiesel on the behavior of a mechanically governed injection system.

For the non-optimized configuration P1B1, where the experimental deviations are the largest (up to approximately 6%), both methods correctly predict an increase in fuel consumption, although with a slightly smaller slope compared with the measured values. This indicates that most of the discrepancy arises from the specific interaction between pump P1 and injector B1 (e.g., nonlinearities in needle lift and pressure-wave reflections), which are not fully captured by the simplified correction factors applied in Methods I and II.

For the optimized configurations (P2B1 and P1B2), where the measured differences range from 1.3% to 3.5%, both methods reproduce the results exceptionally well: Method I predicts an increase of 2.7-3.7%, while Method II yields a wider but still realistic range of 1–5%. The trends, relative ordering of fuels (D-B50-B100), and pressure dependencies fully match the experimental observations. The B50 values, in both the experiments and the predictions, consistently fall between those of B100 and diesel, further confirming the validity of the approach.

Overall, the results show that biodiesel leads to a moderate yet systematic increase in fuel consumption under mechanically governed injection, primarily due to its higher density and the altered hydraulic behavior within the injection system. The comparison demonstrates that both approaches provide a highly reliable estimation of the fuel-consumption difference, with Method I yielding a more conservative (narrower) prediction, while Method II offers a broader but equally physically justified range. This confirms that correlations based on density, speed of sound, and the discharge coefficient represent an adequate foundation for predicting fuel consumption for other biodiesel blends without additional experimental testing.

ACKNOWLEDGMENT

This research was financially supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia (Contract No. 451-03-137/2025-03/200109).

REFERENCES

1. Sidjabat, O., 2013, *Influence of feedstocks in biodiesel production on its physico-chemical properties of product: areview*, Scientific Contribut. Oil & Gas, 36(3), pp. 105-122.
2. Nikolić, B.; Marković, S.; Petrović, N.; Marinković, D.; Jovanović, V., 2025,*Biodiesel and feedstocks - possibilities and characteristics: areview*, Thermal Science 29(5A), pp. 3477-3490.
3. Tamilselvan, P., Nallusamy, N.,Rajkumar, S.,2017, *A comprehensive review on performance, combustion and emission characteristics of biodiesel fuelled diesel engines*, Renewable and Sustainable Energy Reviews, 79, pp. 1134-1159.
4. Zhang, Y., Zhong, Y., Lu, S., Zhang, Z., Tan, D., 2022,*A comprehensive review of the properties, performance, combustion, and emissions of the diesel engine fueled with different generations of biodiesel*. Processes, 10(6), pp. 1178.

5. Damanik,N., Ong,H.C., Tong, C.W., Mahlia, T.M.I., Silitonga, A.S.,2018, *A review on the engine performance and exhaust emission*, Environmental Science and Pollution Research,(25), pp. 15307-15325.
6. Akbari, M., Piri, H., Renzi, M., Bietresato, M., 2024,*The effects of biodiesel on the performance and gas emissions of farm tractors' engines: a systematic review, meta-analysis, and meta-regression*. Energies, 17(17), pp. 4226.
7. Nikolić, B., Jovanović, M., Milanović, S., 2017, *Function K - as a link between fuel flow velocity and fuel pressure, depending on the type of fuel*, Facta Universitatis Series: Mechanical Engineering, 15(1), pp. 119-132.
8. Emmanouilidou, E., et al., 2024, *A comparative study on biodiesel production from edible and non-edible biomasses*, Journal of Molecular Structure, 1306, pp. 137870
9. Sujin, P., et al., 2024,*Optimized biodiesel production from mixed non-edible oils using advanced computational techniques and a novel bifunctional liquified catalyst: compatibility assessment in IC engines*, Biomass and Bioenergy, 190, pp. 107412.
10. Kumar, S., et al., 2023,*Analysis of oil mixing for improvement of biodiesel quality with the application of mixture design method*, Renewable Energy, 202, pp. 809-821.
11. Sujin, P., et al., 2024,*Optimization of engine perform., emiss. and combus. param. by using mixed noned. oil biodiesel with nano-addit. using hybrid techniques*, Energy, 305, pp. 132413.
12. Salvador, F.J., Ruiz, S., Salavert Fernández, JM., De La Morena Borja, J., 2013, *Consequences of using biodiesel on the injection and air-fuel mixing processes in diesel engines*. Proc. of the Institution of Mechanical Engineers, Part D: Journal ofAutomobile Engineering. 227(8), pp. 1130-1141.
13. Dernotte, J., Hespel, C., Foucher, F., Houillé, S., Mounaïm-Rousselle, C., 2012,*Influence of physical fuel properties on the injection rate in a diesel injector*, Fuel, 96, pp. 153-160.
14. Desantes, J.M., Payri, R., García, A., Manin, J., 2009,*Experimental study of biodiesel blends' effects on diesel injection processes*, Energy & Fuels, 23(6), pp. 3227-3235.
15. Tinprabath, P., Hespel, C., Chanchaona, S., Foucher, F., 2013, *Influence of biodiesel and diesel fuel blends on the injection rate and spray injection in non-vaporizing conditions*, SAE Technical Paper 2013-24-0032.

Contact address:
Boban Nikolić
University of Niš
Faculty of Mechanical Engineering
18000 Niš
A. Medvedeva 14
E-mail: boban.nikolic@masfak.ni.ac.rs