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RESEARCH OF THE PHYSICOCHEMICAL PROPERTIES OF FUEL OBTAINED FROM A MIXTURE OF PETROLEUM-BASED DIESEL AND GRAPE SEED OIL BIODIESEL

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ABSTRACT

In this research work, the preparation of an environmentally friendly, internationally compliant bio-component diesel fuel with minimal impact on engine performance and the study of its physicochemical properties were carried out. Fuel oil was hydrocracked at a temperature of 430 °C and a pressure of 4.0 MPa in the presence of a zeolite catalyst, yielding 60.0 wt.% diesel fraction. Grape seed oil was extracted by the cold-pressing method and transesterified with methanol at 65 °C for 120 minutes in the presence of Aydag zeolite as a heterogeneous catalyst, resulting in the synthesis of 92.9 wt.% fatty acid methyl esters (biodiesel). Infrared spectroscopic analysis confirmed the presence of carbonyl (C=O) and ester (C–O) functional groups in the biodiesel. The obtained biodiesel was blended with diesel fuel at volume ratios of 20, 40 and 60 % to prepare B20, B40 and B60 compositions. Key physicochemical properties of the fuels, including density, kinematic and dynamic viscosity, flash point, cetane number, and lubricity, were determined and compared with the requirements of PN-EN 590:2022 and PN-EN 14214+A2:2019-05 standards. It was found that the addition of biodiesel to the diesel fraction leads to a linear increase in density, viscosity, flash point, and cetane number. The cetane number of biodiesel (54.9) was higher than that of conventional diesel fuel, and an 8.93% increase in the cetane number was observed in the B60 composition. The addition of biodiesel to diesel fuel at 20-60 % (by volume) ensures technical compatibility and environmental advantages, making it a viable alternative for the energy- efficient utilization of agro-industrial waste.

Keywords: biodiesel; diesel; transesterification; triglyceride; grape seed.

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1. Introduction

As a result of the rapid development of industrial and transportation infrastructure, global energy demand continues to increase, and a significant portion of energy consumption is still supplied by fossil-based fuels (oil, natural gas, coal, etc.) [1]. The dominance of internal combustion engines in the transportation and industrial sectors has led to a substantial share of global energy demand being met by diesel fuel. According to the report of the International Energy Agency (IEA), the transportation sector accounts for approximately 30% of global energy consumption, and about 75% of this demand is supplied by diesel fuel [2]. Although petroleum-based diesel engine technology is characterized by advantages such as high energy density, stable operating performance, and a well-developed infrastructure network, its combustion releases harmful emissions into the atmosphere, including carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NO_x), sulfur oxides (SO_x), and particulate matter (PM), which contribute to the intensification of environmental problems [3-4].

Studies on bioenergy systems show that biofuels, based on the chemical conversion of lipid-derived substrates, have the highest technological and functional potential for energy production [5-9].

The conversion of plant-derived lipid resources into monoalkyl fatty acid esters (biodiesel) through the transesterification reaction is one of the most extensively studied and industrially applied approaches in biofuel technologies. Biodiesel consists of fatty acid methyl/ethyl esters obtained from renewable plant-based feedstocks via the transesterification process, and its advantages-such as high biodegradability, low toxicity, inherent oxygen content, and carbon neutrality-have been widely confirmed [10, 11].

Various literature sources [12, 13] report that diesel–biodiesel blends can be used in petroleum-based fuel engines without significant modifications or alterations, while ensuring environmental advantages.

In their study, Abbasov M.M. and co-authors [14] scientifically demonstrated the feasibility of producing environmentally cleaner and renewable component-rich “green diesel” and “green gasoline” fractions through the co-processing of vacuum gas oil with cottonseed oil via a mild hydrocracking process. The authors substantiated both

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the deep processing of petroleum-derived feedstock and the effective utilization of vegetable oils as alternative raw materials for fuel production.

In his study, Hoekman S.K. [15] demonstrated that the use of biodiesel significantly reduces particulate matter (PM) emissions; however, in some cases, an increase in nitrogen oxides (NO_x) emissions may be observed, and optimizing the blending ratio can minimize this effect. El-Khatib S. and co-authors [16] reported that biodiesel produced from plant-based oils derived from agro-industrial waste exhibits fuel properties close to those of conventional diesel fuel, along with a significant reduction in engine emissions [17-19].

Knothe G. [20], in his studies, demonstrated that the fatty acid composition and degree of unsaturation directly influence the combustion characteristics, oxidative stability, cetane number, and cold flow properties of biodiesel. He emphasized that biodiesel derived from oils rich in unsaturated fatty acids such as oleic and linoleic acids, due to its high combustion performance, should be blended with petroleum-based diesel in order to optimize the fuel's oxidative stability.

The selection of feedstock for biodiesel production used in fuels blended with petroleum-based diesel is a critically important issue from both environmental and economic perspectives. The use of first-generation biodiesel sources such as corn, sunflower, and rapeseed oil creates a "food-fuel competition," which has led to increasing scientific interest in alternative feedstocks outside the food chain [21]. In this context, the aim of the present study is to evaluate the fuel efficiency of biodiesel obtained from grape seed oil-considered an environmentally and economically favorable feedstock-by blending it with diesel fuel. The grape seed oil was derived from agro-industrial waste generated after wine production at "GANJA SHARAB-2", an enterprise operating in the western region of Azerbaijan. In 2025, this agro-industrial facility generated approximately 65% grape seed waste, making it one of the most promising raw materials for non-food oil production [22]. The method of obtaining oil from grape seeds as an agro-industrial waste and producing biodiesel from this oil has been investigated. Biodiesel obtained from transesterification of grape seed oil was mixed with diesel fuel obtained from hydrocracking of heavy oil residue in amounts of 20, 40, 60% at a temperature of 430°C and a pressure of 4.0 MPa to produce biofuel. In this study, the physicochemical properties of B20, B40, and B60 blend compositions-such as viscosity, density, cetane number, flash point, and other parameters-were analyzed in accordance with international standards PN-EN 590:2022 [23] and PN-EN 14214+A2:2019-05 [24], and their environmental advantages as well as minimal impact on engine performance were evaluated.

2. Experimental section

2.1. Raw material

Diesel raw material - fuel oil obtained as a 50-55 wt.% residual fraction as a result of the primary distillation of Baku crude oils was used. Although most of the fuel oil obtained from Baku oils in the oil industry is used as a raw material for producing lubricating oils, bitumen, pitch, and petroleum coke, it is also considered the main raw material for obtaining diesel to increase the depth of oil refining.

2.2. Diesel production

The hydrocracking process of fuel oil obtained from Baku oils was carried out at a temperature of 430 °C, at a pressure of 4.0 MPa, in a "Hydrocracking of Heavy Oil Residues" (SPR-1) unit consisting of a continuously stirred-tank reactor CSTR system from the German company AMTECH, with the use of a zeolite catalyst taken from the local, natural resource of Azerbaijan, the Imishli region. The CSTR system consists of a reactor with an internal volume of 20 liters, which is continuously homogenized with fuel oil at 80-90 °C and charged with zeolite catalysts and hydrogen prepared in the form of a suspension.

2.3. Raw materials

Plant raw materials - grape seed waste taken after the production process of "GANJA SHARAB-2", an agro-industrial enterprise operating in the western region of Azerbaijan, was used. The seeds were washed and dried on drying papers in a drying oven at a temperature ranging from 25-40 °C for 72 hours. After drying, they were ground in a laboratory mill (SM-450L, MRCLab) to a size of less than 0.50 mm.

2.4. Grape seed oil extraction

The process of oil separation by cold pressing was carried out in a KOMET CA 59G oil press with a capacity of 5-8 kg/h of raw material to be input. The yield of the process was determined according to the mass of oil extracted from 200 g of dried grape seeds.

2.5. Biodiesel production

Biodiesel was produced by transesterification of methanol with grape seed oil in the presence of natural Aydag zeolite taken from the Tovuz region as a heterogeneous catalyst. The transesterification reaction was carried out in a 500 ml three-necked flask equipped with a magnetic stirrer, thermometer, glass dropping funnel and condensation system connected to the flask. The reaction was carried out at a temperature of 65 °C for 2 hours with continuous stirring, and the production of biodiesel was completed.

2.6. Preparation of diesel + biodiesel mixture

In a glass container, first diesel, then biodiesel were added using a magnetic stirrer and mixed for 15–30 minutes at medium speed (400-800 rpm) until a homogeneous phase was obtained. By adding 20, 40, 60 % biodiesel to diesel fuel, mixtures classified as B20, B40, B60 were prepared. Quality research on "B" type fuels obtained by mixing grape seed oil biodiesel with petroleum-based diesel fraction was carried out in accordance with PNEN 590:2022 and PN-EN 14214 + A2:2019-05 standards.

2.7. Research equipment

The physical parameters of the samples taken in the study were determined, such as density at 15 °C, kinematic and dynamic viscosity at 40 °C, ignition temperature and cetane number. The density of the fuels was determined using a density meter equipped with a DA-100M device from Mettler Toledo (Columbus, OH, USA). The effect of temperature on kinematic and dynamic viscosity was determined using an Anton Paar GmbH SVM 3001 Stabinger viscometer equipped with a GRANT thermostatic water bath in the temperature range from -60 °C to +135 °C. The flash point of the fuels and their prepared compositions was determined using a semi-automatic Herzog HFP 380 apparatus. The determination of the cetane number was carried out by an alternative method, using an Irox Diesel analyzer (Grabner Instruments Messtechnik GmbH, Vienna, Austria).

The Infrared (IR) spectra of petroleum-based diesel fraction and grape seed biodiesel were recorded on a zinc-selenide crystal in an Alpha Fourier spectrophotometer manufactured by the German company "BRUKER" and were recorded at room temperature by creating a thin sample layer between KBr crystal plates and using the principle of radiation transmission. The samples were analyzed in the transmission mode, in the wavelength range of 600-4000 cm^{-1}.

3. Results and discussion

One of the main issues facing the modern chemical industry is to save energy resources and raw materials by developing new highly efficient and environmentally friendly processes and technologies. The demand for ever-increasing volumes of gasoline and diesel from high-quality motor fuels is an extremely urgent problem. Therefore, the hydrocracking process is necessary as a recycling process for heavy oil residues. The hydrocracking process of fuel oil without any hydrotreatment in the presence of a directly suspended highly dispersed zeolite catalyst has been studied [25-27]. As a result of the analysis of the hydrocracking processes carried out, it was determined that under optimal conditions (430 °C, 4.0 MPa) the yield of the diesel fraction is 60.0% by mass, respectively (table 1).

As a result of the experiments, 34.7% of grape seed oil was obtained by cold pressing from 200 g of dry weight of grape seeds as raw material.

The process of obtaining biodiesel from grape seed oil by transesterification reaction with methanol in the presence of zeolite catalyst was studied and the material balance of the process is given in table 2. As can be seen from the table, the experiments on transesterification reactions were carried out at a 1:10 Mol ratio of oil to methanol, a catalyst amount of 1.5 g/L, at a temperature of 65 °C and a reaction time of 120 minutes. 92.9% of biodiesel was obtained from the process.

The transesterification reaction of grape seed oil with methanol in the presence of a zeolite catalyst proceeds via an ester exchange mechanism and is characterized by the sequential conversion of triglycerides into diglycerides, monoglycerides, and glycerol. The zeolite catalyst is chemically stable, insoluble in the reaction medium, and can be separated after the reaction by mechanical methods without structural changes, allowing for its reuse. These properties make the transesterification process carried out in the presence of a zeolite catalyst advantageous in terms of both chemical efficiency and environmental sustainability [28].

The general transesterification reaction can be represented by the following mechanism (fig. 1) [29]:

Grape seed oil biodiesel is a renewable fuel obtained by transesterification of vegetable oil and naturally contains oxygen molecules. This oxygen ensures a more complete combustion process and consequently significantly reduces CO, HC (hydrocarbons) and PM emissions. On the other hand, since biodiesel is of natural vegetable origin, the CO_2 produced by its combustion does not add additional carbon to the atmosphere, as this carbon is returned to the biomass through the photosynthesis cycle. Thus, biodiesel is considered a "carbon neutral fuel" compared to diesel [30].

Although petroleum-based diesel and biodiesel are functionally similar energy carriers, they differ significantly in terms of chemical composition and molecular structure, which directly affects their combustion mechanisms, emission profiles, and physicochemical properties. Petroleum-derived diesel is a complex mixture of hydrocarbons, mainly consisting of alkanes, cycloalkanes, and aromatic compounds within the C_{10}–C_{22} range. It contains no oxygen atoms and is generally characterized by empirical formulas such as C_nH_{2n+2} and C_nH_{2n}. While aromatic components provide high calorific value, they can also lead to increased formation of particulate matter and polycyclic aromatic hydrocarbons during combustion. In contrast, biodiesel consists of monoalkyl (primarily methyl) esters of fatty acids derived from vegetable oils and has the general structure $R–COOCH_3$. The presence of approximately 10-12 % oxygen in its composition fundamentally distinguishes it from conventional diesel. The existence of oxygenated, polar ester groups promotes more complete combustion, resulting in reduced emissions of CO, HC, and particulate matter, thereby highlighting the environmental advantages of biodiesel.

In order to address the limitations associated with the use of petroleum-based diesel fuel and to overcome the aforementioned problems, a comparative study of the physicochemical properties of diesel fuel obtained via direct low-pressure hydrocracking of heavy petroleum residue (fuel

Table 1

Material balance of the hydrocracking process in diesel production

Catalyst	P_{H_2}, MPa	*T*, °C	Yield of products, % mass					
Zeolite 2.5%	4.0	430	Gas C_1–C_4	Gasoline i.b.p.-200 °C	Fr. 200-360 °C	Σ fr. < 360 °C	Residue > 360 °C	Coke
			7.0	32.0	28.0	60.0	28.5	4.5

Table 2

Material balance of the transesterification process in the production of biodiesel

Raw materials	Amount of catalyst, g/L	Molar ratio of oil:methanol	The reaction temperature, °C	Reaction time, min.	Extraction of methyl ester of fatty acids, %	Glycerin yield, %
Grape seed oil	1.5	1:10	65	120	92.9	6.3

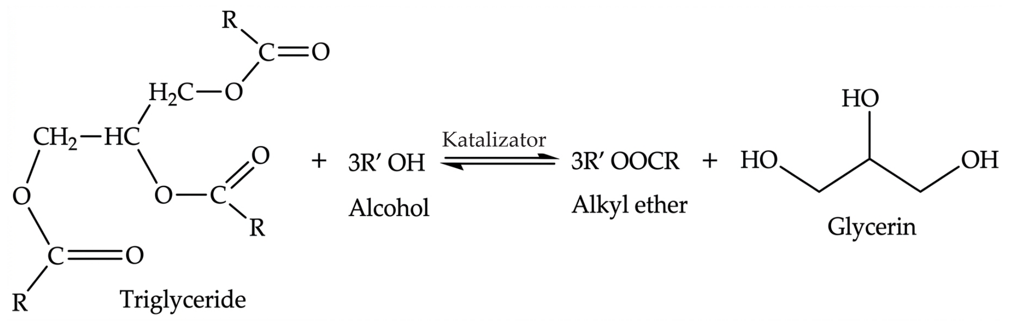

Fig. 1. Mechanism of the transesterification reaction

oil) and biodiesel produced through the transesterification process was carried out using various methods (table 3). As shown in the table, the biodiesel derived from grape seed oil has a density of 891.1234 kg/m^3, a kinematic viscosity of 4.7645 mm^2/s, and a cetane number of 54.9, whereas the diesel fraction obtained from mazut hydrocracking has a density of 836.6527 kg/m^3, a kinematic viscosity of 3.1121 mm^2/s, and a cetane number of 50.4. At the same time, the sulfur content in biodiesel is also relatively low. This is due to the differences in fuel composition: biodiesel derived from grape seed oil consists mainly of complex esters, while diesel obtained from mazut is primarily composed of saturated and unsaturated hydrocarbons. The use of biofuels produced from vegetable oils is based on the differences in their physical and chemical properties compared to those of diesel fractions derived from heavy petroleum residues such as mazut [31-33].

As a result of the conducted analyses, it was proven that grape seed oil biodiesel, as a triglyceride-containing or vegetable fuel, has a higher density, viscosity and lower thermal values, volatility compared to diesel fuel [34].

The composition of petroleum-based diesel fuel and grape seed oil biodiesel was analyzed qualitatively by Infrared (IR) spectroscopic method based on the determination of vibrational signals of functional groups. The results of IR spectra for diesel fuel and grape seed oil biodiesel are presented in figure 2. The main chemical bonds and functional groups for both fuels are also indicated in the figure based on the spectra and the identification results of the relevant studies. The spectra belonging to each sample presented in the figure clearly showed that their chemical compositions are completely different. In particular, the strong peak observed in the range of 1740-1750 cm^{-1} belongs to the carbonyl (C=O) functional group of biodiesel (methyl ester of fatty acids), and the intensity and area of the peak also increase sequentially. The result of this analysis indicates that the transesterification reaction has successfully occurred and triglycerides have been converted into methyl esters. The enhancement of the C–O (C–O–C/O–CH$_3$) signals in the region of 1170–1260 cm^{-1} also confirms the formation of ether bonds and correlates with the peak at 1746 cm^{-1}. Since diesel mainly consists of saturated and unsaturated hydrocarbons, these oxygen signals in the spectrum of the sample are very weak and can even be noted as non-existent. However, CH$_2$/CH$_3$ vibrations are present in the region of 2850–2950 cm^{-1} and 1460–1375 cm^{-1}, which is consistent with the presence of long saturated and unsaturated hydrocarbon chains in diesel.

Based on these physicochemical indicators, we can note that when biofuel is used instead of diesel fuel in diesel engines, problems such as flow problems, poor atomization, clogging of injectors, thickening of the lubricating oil, incomplete combustion and loss of power limit its use. To solve these problems, fuel consisting of B20, B40, B60 mixtures was prepared by adding 20, 40, 60 % biodiesel obtained from grape seed oil to the petroleum-based diesel fraction. The quality study on type "B" fuels obtained by blending grape seed oil biodiesel with petroleum-based diesel fraction was conducted in accordance with the PNEN 590:2022 and PN-EN 14214+A2:2019-05 standards. Blending diesel fuel with biodiesel aims to optimize the physicochemical properties of engine fuel and ensure a cleaner combustion process from an ecological point of view.

A comparative study of the physicochemical properties of the fuel consisting of the obtained B20, B40, B60 mixtures and an analysis of the effect of the mixture on the ecological, physicochemical indicators were carried out. Among the physicochemical properties of biodiesel fuel, the most important are those that affect the values of engine performance indicators, in particular, exhaust gas emissions. These include density, kinematic viscosity, cetane number and ignition temperature. The analyses conducted on the

Table 3
Physico-chemical characteristics of fuel

Property	Diesel fuel	Grape seed biodiesel
Density at 15 °C (kg/m^3)	836.6527	891.1234
Kinematic viscosity at 40 °C (mm^2/s)	3.1121	4.7645
Irradiance coefficient 20 °C	1.4777	1.9876
Heating value (MJ kg^{-1})	44.631	39.493
10% Residual coke formation (%)	0.4	0.4
Cetane number	50.4	54.9
Sulphated ash (% mass)	0.02	0.02
Water (% mass)	-	0.001
Sulfur (% mass)	0.18	<0.001
Flash point (°C)	55	150
Pour point (°C)	-25	-10
Iodine value (g I$_2$/100 g)	12	100.4
Free glycerol (% m/m)	-	0.2
Composition (% mass) C H O	 86.2 13.8 -	 77.3 10.7 12.0

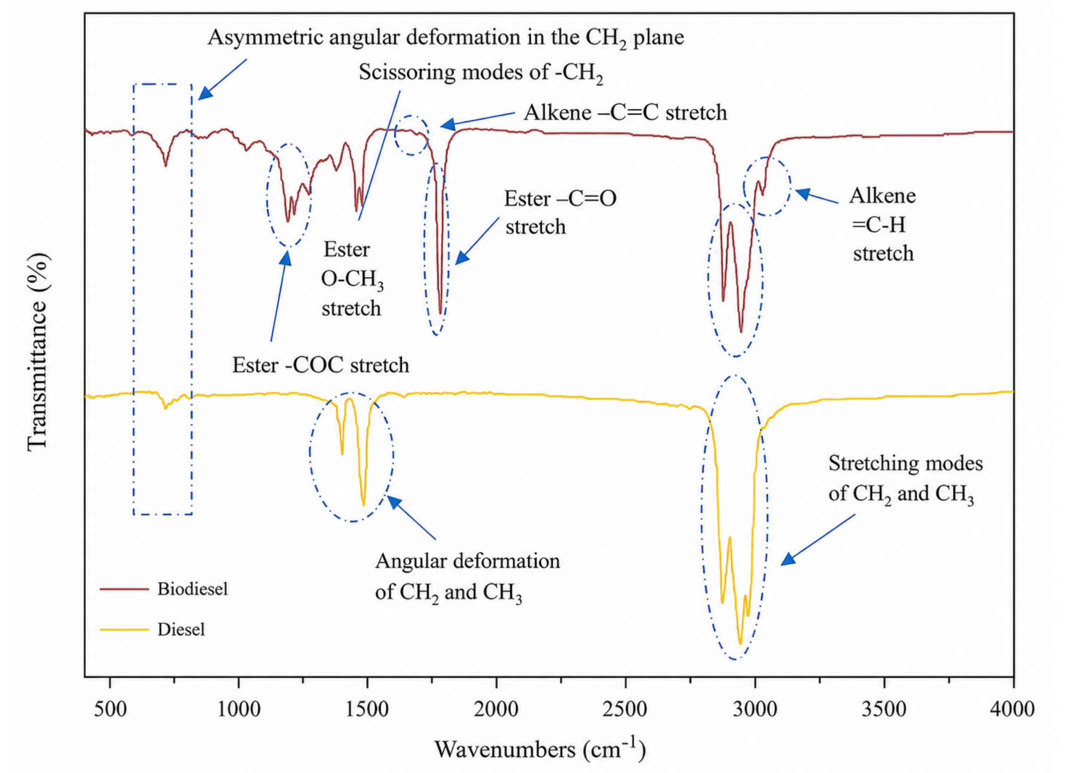

Fig. 2. IR spectra of diesel fuel and grape seed oil biodiesel

B20, B40, B60 mixtures allow us to determine changes in their density, viscosity, ignition temperature, cetane number and other important indicators, as well as to assess the application possibilities of the mixture as a fuel.

Density

Density is one of the main physical parameters that should be investigated because it plays an important role in the quality of the fuel. Density was measured at 15 °C by dividing the mass of each sample by a fixed volume of 20 ml. The density value was determined with a measurement uncertainty of ±0.1 kg/m^3. Figure 3 presents the density values of the following samples: petroleum-based diesel, grape seed oil biodiesel, and fuel density values of combinations of grape seed oil biodiesel and petroleum-based diesel (B20, B40, B60). The volume content of biodiesel in these diesel blends was 20, 40, and 60 %. The density of the obtained biodiesel samples was within the range of the standard density values specified in ASTM D6751 and EN14214, which is between 820 and 900 kg/m^3 [35]. The density of grape seed oil biodiesel increases by approximately 7.5% when blended with diesel fraction. Adding grape seed oil biodiesel to diesel fraction increases the density of fuels consisting of a mixture of B20, B40, B60. The density of B60 fuel is 851.2142 kg/m^3, which is approximately 1.7% higher than that of diesel. This is explained by the presence of oxygenated functional groups in biodiesel. Since the density of biodiesel (891.1234 kg/m^3) is higher than that of diesel fuel (836.6527 kg/m^3), the total density also increases as the proportion of biodiesel in the blend increases (B20, B40, B60, etc.). For this experiment, 840.5671 kg/m^3 was taken for B20 and 845.8671 kg/m^3 for B40 biodiesel. High-density biodiesel blends significantly affect the performance of fuel pumps, fuel filters, and compression ignition engines, improving air-fuel mixing efficiency and combustion efficiency [36]. Injector systems, pumps, and injectors provide precise control of the fuel quantity to ensure proper combustion, depending on the density of the biodiesel.

Kinematic viscosity

Kinematic viscosity is of particular importance in the characterization of biodiesel, since a suitable numerical viscosity facilitates the flow of the fuel, which mainly affects the functionality of fuel injection systems at low temperatures [37]. Excessively high viscosity leads to poor atomization of the fuel, which leads to the formation of deposits and soot [38]. Dynamic viscosity was measured in the study, since it is a physical parameter that evaluates the resistance of the fuel to flow in the injection system during fuel flow at high pressures and speeds. This parameter is an indicator of the resistance of the fluid to flow or deformation and also affects the jet penetration and lubricating properties in the combustion chamber of the engine. Figure 4 presents the measurement parameters of the dynamic viscosity of petroleum-based diesel, grape seed oil biodiesel and a blended composition of

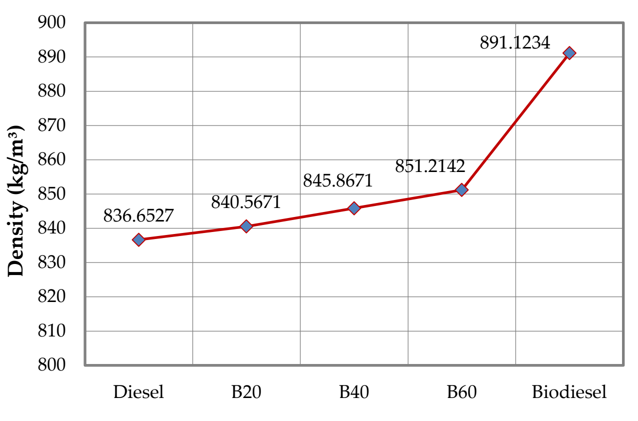

Fig. 3. Density of diesel, biodiesel, B20, B40, B60 fuels

B20, B40, B60. As can be seen from the figure, in the presented dynamic viscosity measurement results, the petroleum-based diesel fraction has the lowest viscosity (12 mm²/s), while B20 (45 mm²/s) and B40 (50 mm²/s) fuels have slightly higher viscosity. The highest viscosity was recorded for grape seed oil biodiesel (160 MPa/s). Blending various increasing volumes of grape seed oil biodiesel into the diesel fraction led to an increase in viscosity. In the temperature range above 10°C, the changes in the viscosity of grape seed oil biodiesel showed a predominantly linear character. However, in the temperature range from approximately 10 °C to -20 °C, the viscosity of biodiesel exhibited a parabolic characteristic. As a result of the analyses conducted, we can note that the application of B20, B40, B60, obtained from a mixture of grape seed oil biodiesel and petroleum-based diesel as fuel in the summer or spring-autumn seasons will not cause a significant increase in fuel flow resistance in the fuel system or a significant deterioration in injector, atomization and combustion conditions.

The kinematic viscosities of the synthesized fuels were also determined. The analyses were carried out at a temperature of 40 °C in accordance with the requirements of the PN-EN ISO 3104 standard. Figure 5 presents the results of the kinematic viscosity indicators of diesel fraction, grape seed oil biodiesel and their blends: B20, B40 and B60 fuels in the form of a diagram. As can be seen from the figure, 3.1121, 3.2611, 3.4321, 3.5811 and 4.7645 mm²/s indicate the kinematic viscosity of diesel, B20, B40, B60 and biodiesel, respectively. The viscosity of B20 is 3.2611 mm²/s, while the viscosity of B40 biodiesel is 3.4321 mm²/s, and B60 is 3.5811 mm²/s. According to the international standard PN-EN ISO 3104, the viscosity range for biodiesel should be between 1.9 and 6.0 mm²/s. The kinematic viscosity of B20, B40 and B60 biodiesel compositions was shown to be in this range. The relationship between kinematic viscosity and biodiesel level in the samples shows that as the volume level of biodiesel in biodiesel compositions increases, the kinematic viscosity also increases. This leads to the preparation of blends of diesel-biodiesel compositions with a higher biodiesel volume. The kinematic viscosity of grape seed oil biodiesel is 1.6524 units higher than that of diesel, which indicates that the resulting biodiesel is characterized by a somewhat higher flow resistance than petroleum-based diesel at a temperature of 40°C. It should be noted that all tested fuels meet the requirements of the PN-EN-590 and PN-EN 14214 standards for diesel fraction and biodiesel.

Flash point

The ignition temperature is defined as the minimum temperature at which the fuel vapor and air mixture can be ignited by an external ignition source during the fuel heating process. It does not directly affect the combustion process, but it increases the safety of biodiesel during storage and transportation. At the same time, it prevents the formation of vapor jams by eliminating fuel evaporation during cold engine start-up [39]. Figure 6 shows the ignition temperatures of petroleum-based diesel, grape seed oil biodiesel, and B20, B40, and B60 blended fuels.

As can be seen from the figure, the diesel blend B20 with petroleum-based diesel fuel and 20% grape seed oil biodiesel additive was characterized by the lowest ignition temperatures of 55 °C and 58 °C. When the biodiesel ratio in the diesel fuel mixture was increased to 40%, the ignition temperature increased to 65 °C, and when it was increased to 60%, it was 70 °C. This is due to the initial evaporation of diesel fuel molecules. The ignition temperature of grape seed oil biodiesel is 150 °C, which is 3 times higher than the ignition temperature of diesel fuel and even higher than the minimum limit specified in biodiesel standards [40]. According to the EN 14214 standard, the ignition temperature of biodiesel should not be less than 101 °C. The increase in ignition temperature with the gradual addition of biodiesel to the diesel blend is due to the evaporation of fuel components and the formation of a fuel-air mixture at a

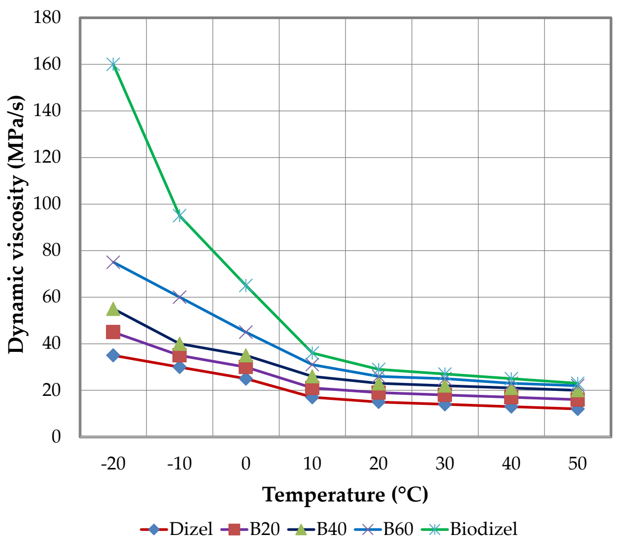

Fig. 4. Study of dynamic viscosity of diesel, biodiesel, B20, B40, B60 fuels as a function of temperature

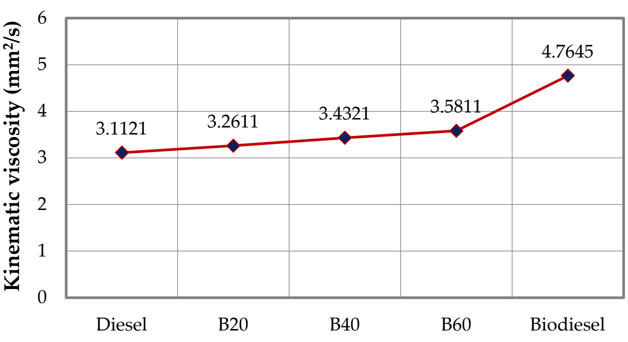

Fig. 5. Kinematic viscosity of diesel, biodiesel, B20, B40, B60 fuels

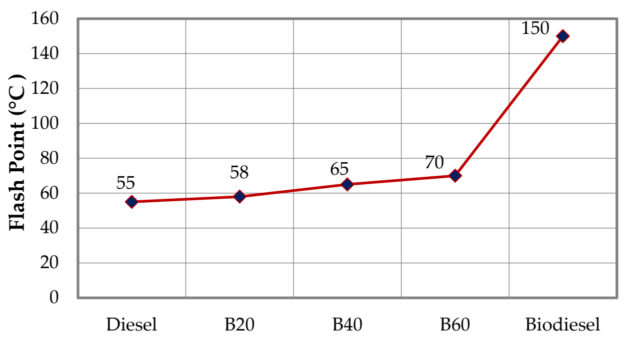

Fig. 6. Flash temperature of diesel, biodiesel, B20, B40, B60 fuels

higher temperature. This will affect the combustion process, especially at low temperatures in the engine cylinder.

Cetane number

The cetane number is a key parameter used to evaluate the auto-ignition ability of diesel fuel in an engine. A higher cetane number can positively influence engine performance, as well as reduce harmful emissions and noise levels. It determines the ignition delay during fuel injection into the combustion chamber, which depends on the carbon chain length and the degree of unsaturation of fatty acids. A low cetane number increases ignition delay and, consequently, raises the likelihood of knocking combustion in diesel engines. In contrast, a high cetane number contributes to reduced exhaust smoke opacity and improved ignition under cold-start conditions.

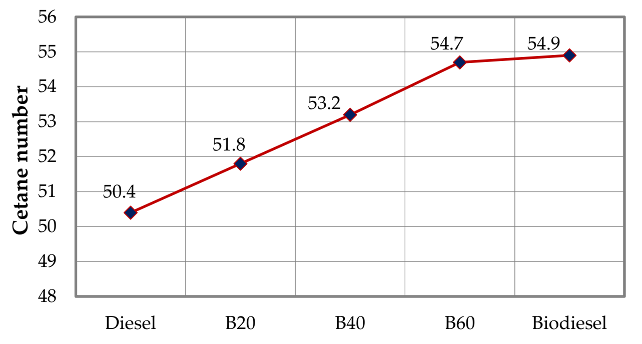

Fig. 7. Cetane number of diesel, biodiesel, B20, B40, B60 fuels

Biodiesel generally exhibits a higher cetane number due to the presence of oxygen-containing ester compounds and a more ordered molecular structure. Upon heating, these structures facilitate the formation of reactive radicals that accelerate auto-ignition. This composition also promotes faster and more complete combustion once the fuel enters the piston–cylinder system. According to various literature sources [41], the cetane number of biodiesel is typically higher than that of conventional diesel fuel. The cetane numbers of petroleum-based diesel, grape seed oil biodiesel, and their blends (B20, B40, and B60) are presented in Figure 7. As shown in the experimental results, blending methyl esters derived from grape seed oil with diesel fuel leads to a linear increase in the cetane number. The cetane number of diesel fuel was determined to be 50.4, while the diesel–biodiesel blends showed increasing values depending on biodiesel content, reaching 53.2 for the B40 blend. According to the international EN 14214 standard, the minimum cetane number for biodiesel should not be less than 51. The measured cetane numbers of the samples are fully consistent with the EN 14214 standard and literature data [42]. The increase in cetane number is closely related to the molecular structure of the fuel. Straight-chain compounds generally exhibit higher cetane numbers, whereas branched and aromatic structures tend to resist auto-ignition, thereby lowering the cetane number [43]. The chemical structure of biodiesel derived from grape seed oil (fatty acid methyl esters) is directly linked to its cetane number. The dominant components of this biodiesel are long-chain, predominantly linear, and slightly branched molecules. Such structures decompose more readily under compression, forming active radicals that reduce ignition delay and increase the cetane number. Additionally, the presence of oxygen atoms in the molecular structure accelerates combustion by facilitating initial oxidation reactions. In contrast, highly branched structures increase molecular stability, making ignition more difficult and reducing the cetane number [44]. The primary fuel, biodiesel obtained from grape seed oil, reached a cetane number of 54.9, which is higher than that of diesel fuel (50.4). Furthermore, the results show that as the proportion of grape seed biodiesel in the fuel blend increases, the cetane number also increases. This can be explained by the higher fraction of linear and oxygenated compounds in the blend, which experimentally leads to an increase in the cetane number.

Conclusions

As a result of mazut hydrocracking, 60.0 wt.% petroleum-based diesel fraction was obtained, while 92.9% biodiesel were produced via transesterification of grape seed oil. Diesel–biodiesel blends (B20, B40, B60) were prepared and comparatively analyzed. Although an increase in the volumetric proportion of biodiesel led to higher dynamic and kinematic viscosity, petroleum-based diesel and its blends complied with the PN-EN 590 standard, while biodiesel met the requirements of the PN-EN 14214 standard. The cetane number of the diesel fraction was 50.4, and with the addition of biodiesel, this value increased by 4.5 units (8.93%) in the B60 blend. A linear relationship was also established between the increase in biodiesel content and the flash point. Grape seed oil, as an agro-industrial waste, represents an economically and environmentally viable feedstock for biodiesel production, and its use as an eco-friendly component in diesel fuel is recommended for application as engine fuel.

References

1. Atadashi, I. M., Aroua, M. K., Aziz, A. A. (2016). Biodiesel fuel production by transesterification. *Energy Conversion and Management*, 118, 203-226.

2. Global Critical Minerals Outlook 2025. International Energy Agency (IEA) Publications. www.iea.org

3. Zhu, S., Zhang, K., Deng, K. (2020). A review of waste heat recovery from the marine engine with highly efficient bottoming power cycles. *Renewable and Sustainable Energy Reviews*, 120, 109611.

4. Singh, S. P., Singh, D. (2016). Biodiesel production through the use of different sources and characterization of oils

and their esters as the substitute of diesel: A review. *Renewable and Sustainable Energy Reviews*, 14, 200-216.

5. Wang, Y., Cansu Acarturk, B., Burris, L., et al. (2022). Physicochemical characterization of unconventional fly ashes. *Fuel*, 316, 123318.

6. Celik, M., Iskender, A. (2020). Combustion and emissions of B20 blend. *Fuel*, 279, 118507.

7. Demirbaş, A. (2020). Progress and recent trends in biodiesel fuels. *Energy Conversion and Management*, 209, 112699.

8. Gharehghani, A., Jazayeri, S. A. (2021). Performance of CI engine on biodiesel blends. *Energy Reports*, 7, 5562–5577.

9. Monfaredi, K., Emami Niri, M., Sedaee, B. (2020). Improving forecast uncertainty quantification by incorporating production history and using a modified ranking method of geostatistical realizations. *Journal of Energy Resources Technology*, 142(9), 093004.

10. Dhar, A., Agarwal, A. K. (2021). Combustion characteristics of biodiesel fuelled engines. *Fuel*, 289, 119894.

11. Dwivedi, G., Sharma, M. P., Jain, S. (2017). Diesel engine performance with biodiesel blends. *Renewable and Sustainable Energy Reviews*, 33, 233–250.

12. Ashraful, A. M. (2015). Engine performance and life cycle assessment of biodiesel. *Renewable Energy*, 81, 830–845.

13. Khalife, E. (2017). Impact of B20 and B40 fuels. *Energy Conversion and Management*, 153, 96–106.

14. Abbasov, M. M., Mammadova, T. A. (2018). Obtaining of “green diesel” and “green gasoline” in the process of light hydrocracking of vacuum gasoil with cottonseed oil *Chemical Problems*, 1, 119–125.

15. Hoekman, S. K. (2012). Biofuels in the U.S. – Challenges and opportunities. *Renewable Energy*, 36(1), 22–30.

16. El-Khatib, S., Ahmad, M. N., Ahmad, M. Z., et al. (2021). A comprehensive review on biodiesel production, fuel properties, engine performance and emission characteristics. *Journal of Cleaner Production*, 297, 126849.

17. Atabani, A. E., Silitonga, A. S., Badruddin, I. A., et al. (2012). A comprehensive review on biodiesel as an alternative energy resource and its characteristics. *Renewable and Sustainable Energy Reviews*, 16(4), 2070–2093.

18. Qi, D. (2019). Emissions with biodiesel blends. *Fuel,* 235, 1031–1041.

19. Sajjad, H. (2022). Biodiesel blends in common rail engines. *Energy*, 255, 124623.

20. Knothe, G. (2010). Biodiesel and renewable diesel: A comparison. *Progress in Energy and Combustion Science*, 36(3), 364–373.

21. Sathish Kumar, V. (2021). Combustion and performance of biodiesel blends. *Applied Energy*, 295, 117052.

22. Mani, M., Nagarajan, G. (2018). Diesel engine test with biodiesel blends. *Fuel*, 214, 18–25.

23. PN-EN 590:2022-08. (2022). Automotive fuels-diesel fuels-requirements and test methods. *Warsaw, Poland: The Polish Committee for Standardization.*

24. PN-EN 14214+A2:2019-05. (2019). Liquid petroleum products-fatty acid methyl esters (FAME) for use in automotive compression-ignition (diesel) engines and heating applications-requirements and test methods. *Warsaw, Poland: The Polish Committee for Standardization.*

25. Carraretto, C. (2021). Biodiesel–diesel blends in marine engines. *Energy*, 236, 121525.

26. Suleymanova, A. B., Mukhtarova, G. S., Zafar, M., et al. (2025). Structure activity correlation of modified zeolite catalysts in biodiesel synthesis. *Ctalysis Letters*, 155 (381), 155–381.

27. Mukhtarova, G. S., Suleymanova, A. B. (2025). Research of physical-chemical properties of biodiesel fraction obtained from agro-industrial waste. *Processes of Petrochemistry and Oil Refining*, 26(2), 564–573.

28. Mukhtarova, G. S., Suleymanova, A. B. (2024). Study of biodiesel obtained from agro-industrial waste. *Processes of Petrochemistry and Oil Refining*, 25(3), 666–674.

29. Mukhtarova, G. S., Hasanova, A. B., Ibrahimova, Z. M. (2023). Hydrocracking of heavy oil residues with the participation of Ni-bentonite. *SOCAR Proceedings*, 3, 156–163.

30. Qi, D. (2021). NOx emission control strategies. *Renewable Energy*, 180, 1356–1368.

31. Rakopoulos, D. C. (2017). Study of biodiesel blends in CI engines. *Energy Conversion and Management*, 154, 470–487.

32. Sanjid, A. (2020). Comparative performance of B10–B50. *Fuel*, 276, 118002.

33. Roy, M. M. (2022). Biodiesel blends cold flow properties. *Renewable Energy*, 185, 1242–1253.

34. Habibullah, M. (2015). Atomization and spray of B20–B40. *Fuel*, 153, 435–444.

35. Xue, J. (2019). Review on biodiesel engine performance. *Renewable and Sustainable Energy Reviews*, 81, 555–567.

36. Imran, A. (2020). B20 combustion analysis. *Energy Sources A*, 42(19), 2431–2444.

37. Ong, H. C. (2020). Next-gen biofuel blends. *Energy Conversion and Management*, 203, 112280.

38. Basha, S. A. (2021). Neem biodiesel blends. *Fuel*, 305, 121614.

39. Nantha Gopal, K. (2014). Comparative study of biodiesel blends. *Renewable and Sustainable Energy Reviews*, 28, 441–455.

40. Oguz, H. (2022). Turbodiesel tests with biodiesel blends. *Fuel*, 324, 124567.

41. Ali, O. M. (2021). Palm biodiesel engine performance. *Energy*, 228, 120480.

42. Nisar, N., Mehmood, S., Nisar, H., et al. (2018). Brassicaceae family oil methyl esters blended with ultra-low sulphur diesel fuel (ULSD): Comparison of fuel properties with fuel standards. *Renewable Energy*, 117, 393–403.

43. Knothe, G. (2005). Dependence of biodiesel fuel properties on the structure of fatty acid alkyl esters. *Fuel Processing Technology*, 86, 1059–1070.

44. Ramos, M. J., Fernandez, C. M., Casas, A., et al. (2009). Influence of fatty acid composition of raw materials on biodiesel properties. *Bioresource Technology*, 100, 261–268.