Tikrit Journal of Engineering Sciences (2025); 32(Sp1): 2635
DOI: http://doi.org/10.25130/tjes.sp1.2025.42

IRAQI Academic Scientific Journals

ISSN: 1813-162X (Print); 2312-7589 (Online)

Tikrit Journal of Engineering Sciences

available online at: http://www.tj-es.com

TJES Tikrit Journal of Engineering Sciences

Use of Linseed Oil Additives in Diesel Fuel to Reduce Greenhouse Gas Emissions

I.V. Gordienko [*a], *S.N. Kharchenko* [b], *D.Kh. Mirkhamitova* [c], *B.B. Xakimov* [d], *A.S. Apatenko* [e]

a Admiral Ushakov Maritime State University, Novorossiysk, Krasnodar region, Russian Federation.
b I.T. Trubilin Kuban State Agrarian University, Krasnodar, Russian Federation.
c Almalyk branch of Tashkent State Technical University named after Islam Karimov, Almalyk, Uzbekistan.
d Tashkent Institute of Irrigation and Agricultural Mechanization Engineers, Tashkent, Uzbekistan.
e Russian State Agrarian University – Moscow Timiryazev Agricultural Academy, Moscow, Russian Federation.

Keywords:
Biofuels; Linseed oil; Diesel engine; Blended fuels; Emissions; Environment; Fuel efficiency; Alternative fuels.

Highlights:
- *Adding linseed oil to diesel fuel reduced exhaust gas opacity by up to 36% in peak torque mode.*
- *The use of blended biofuel decreased nitrogen oxide emissions by 17% without compromising engine efficiency.*
- *Long-term engine tests showed a 5% reduction in piston ring wear when operating on linseed oil–diesel blends.*

ARTICLE INFO

Article history:

Received	09 Jul.	2025
Received in revised form	17 Sep.	2025
Accepted	30 Dec.	2025
Final Proofreading	30 Dec.	2025
Available online	31 Dec.	2025

Citation: Gordienko IV, Kharchenko SN, Mirkhamitova DK, Xakimov BB, Apatenko AS. **Use of Linseed Oil Additives in Diesel Fuel to Reduce Greenhouse Gas Emissions**. *Tikrit Journal of Engineering Sciences* 2025; **32**(Sp1): 2635.
http://doi.org/10.25130/tjes.sp1.2025.42

***Corresponding author:**

I.V. Gordienko

Admiral Ushakov Maritime State University, Novorossiysk, Krasnodar region, Russian Federation.

Abstract: In the context of fossil fuel depletion and growing environmental concerns, the study of alternative energy sources, especially biofuels, is particularly significant. Given the global challenges, this work examines the effects of a blended biofuel produced by adding linseed oil to diesel on the operational and environmental performance of a diesel engine. During the experiments, the physical and chemical properties of the initial components and their mixtures were determined, followed by engine testing on the engine stand in the external speed characteristic mode and in a 13-stage test cycle. Evaluation of the data obtained showed that the addition of linseed oil reduced exhaust gas smoke opacity and nitrogen oxide emissions, while causing a slight increase in fuel consumption and in carbon monoxide and unburned hydrocarbon emissions. To balance these effects, optimisation of the blended biofuel composition using the convolution method determined the optimal component ratio, achieving the best balance between fuel efficiency and reduced harmful emissions. The results of the study demonstrate that the use of linseed oil as a component of blended biofuel for diesel engines has the potential to mitigate the environmental impacts of transport.

1.INTRODUCTION

Growing concerns about fossil-fuel depletion and air-quality standards have accelerated the search for practical low-carbon options for compression-ignition engines. Among the available pathways, blending small fractions of vegetable oils with petroleum diesel is an attractive option because it leverages existing engine platforms and fuel logistics while avoiding the capital and energy requirements of full transesterification. Linseed (flaxseed) oil is particularly promising in regions where flax cultivation is established, offering high oil yield and favourable cost; however, its high degree of unsaturation entails storage-stability constraints that must be managed operationally. In this context, the present study evaluates how adding 4–10 vol% of linseed oil to diesel affects the performance and emissions of a YaMZ-534 engine under an external speed characteristic and the UNECE R49 13-mode cycle [1-3]. The global market for vegetable oils has grown significantly in recent decades, reflecting increasing interest in their use. Oils are used for energy, and biofuels derived from vegetable oils represent a promising direction. There are several ways to address dependence on fossil fuels and mitigate their environmental impacts. One is the development and implementation of electric and hybrid vehicles, which reduce greenhouse gas emissions and dependence on oil on a widespread scale. Adoption of electric cars requires substantial investment in charging infrastructure and solutions to address limited range and charging times. Another direction is the use of synthetic fuels obtained from renewable energy sources, such as hydrogen. The advantage of this approach is the ability to leverage existing infrastructure for fuel transportation and storage. However, hydrogen production is energy-intensive and requires substantial electricity. In addition, the widespread use of synthetic fuels requires the development of new technologies and a decrease in their cost [4–6]. The use of vegetable oils as biofuels is attractive. This allows the use of existing diesel engines without modification. Direct use of vegetable oils can cause problems. This is due to the high viscosity and the tendency of oils to polymerize. Deposits can form in the engine, affecting engine efficiency; transesterification of oils provides an effective solution to this problem. Biodiesel shares properties with conventional fuels. In contrast, another option is a mixed biofuel, a blend of oil and petroleum-based fuels [2]. Mixed biofuel can improve engine performance. It is essential to choose the right biofuel composition. One promising vegetable oil for producing mixed biofuel is linseed oil. Flax is a traditional agricultural crop in Russia, and its cultivation does not require high costs or special technologies. Flax seeds contain a significant amount of oil, with oil content reaching 50% or higher, making flax an attractive feedstock for biofuel production. It is also a drying oil with wide applications, used for technical purposes and as a motor fuel. The advantage of linseed oil is its relatively low cost and ready availability, which makes it economically attractive for biofuel production. At the same time, linseed oil has disadvantages, such as low oxidative stability, which limits its storage. Expired linseed oil can be used as fuel, reducing the requirements for its storage and disposal [7–11]. The purpose of this work is to analyse the performance of a diesel engine operating on blends of diesel fuel and linseed oil at varying proportions. This study is limited to exhaust emissions and performance of a compression-ignition engine operating on linseed-oil/diesel blends; it does not involve the production, separation, or utilisation of synthesis gas (syngas), nor the generation of any retentate/permeate streams. In this context, recent summaries indicate that iron-based Fischer–Tropsch (FT) catalysts operate robustly at low H_2/CO ratios near unity (≈0.9–1.3). Therefore, a syngas stream with H_2/CO in the range 1.12–1.15 would be directly compatible with iron-based FT, requiring minimal or no upstream water-gas-shift adjustment.

2.RESEARCH METHODS

A set of experiments was conducted to study biofuels and to investigate the effect of mixed biofuels on engine performance. Unrefined linseed oil "Aroma Vita" was used and mixed with L-grade diesel fuel in accordance with GOST 305-82. At the first stage, the physicochemical properties of the original components (diesel fuel and linseed oil) and their mixtures containing 4, 7, and 10% linseed oil by volume were determined. The density at 20 °C, the kinematic viscosity at 20 °C, the net calorific value, the amount of air required for combustion, and the mass contents of carbon, hydrogen, oxygen, and sulphur were measured. Standard laboratory equipment was used to determine the physicochemical properties of mixtures of linseed oil and diesel fuel, ensuring the required measurement accuracy. The density was measured using a hydrometer or a digital density meter (Anton Paar DMA 4500 M). Measurements were carried out at a precisely controlled temperature of 20°C using a thermostat. The kinematic viscosity was determined using a Brookfield DV2T rotational viscometer. Measurements were carried out at a precisely controlled temperature. The net calorific value was determined using a Parr 6200 bomb calorimeter. The amount of air required for combustion was calculated from the fuel's elemental analysis data and the chemical combustion equations. The mass fractions of carbon, hydrogen, oxygen, and sulfur were determined using an Elemental Vario EL cube elemental analyser. All devices were pre-calibrated, and measurements were repeated several times; the average values were calculated. In the second part of the work, experiments were conducted on a YaMZ-534 diesel engine. The engine was developed by the Yaroslavl Motor Plant (YaMZ). It is a four-stroke inline-four-cylinder engine used in medium-tonnage cars and buses. The engine is equipped with a forced-type water cooling system, an oil filtration system, and turbocharging. Mixture formation is by direct injection. The valve timing mechanism is of the overhead valve type. The injectors and sprayers conform to the YaMZ-534 engine specifications. The diesel engine was tested on an engine test bench under various operating modes, including an external speed characteristic and a 13-stage cycle in accordance with UNECE Regulation 49. The smoke content of the exhaust gases was measured using a Hartridge MK-3 smoke meter. The concentrations of NOx, CO, and CHx were determined using a Yanaco SAE-7532 gas analyser [14]. The gas analyzer data allowed us to evaluate the exhaust composition. These measurements refer exclusively to engine exhaust gases and must not be conflated with the syngas composition. No reformer, gasifier, membrane unit, or any other device producing retentate/permeate streams was employed in these experiments. Using the same settings ensured that the results could be compared. The tests allowed us to evaluate the effect of different fuels. The data obtained will enable us to analyse the engine characteristics. All scalar quantities reported in Tables 2–5 and in the text are presented as mean ± standard deviation (SD) based on n = 3 independent repetitions at each test point. For derived quantities, uncertainties were propagated using the first-order Taylor expansion. The confidence intervals were reported as 95% two-sided CIs, computed as mean ± $t_{0.975,\nu}\cdot SD/\sqrt{n}$, with $\nu = n - 1$. Instrumental uncertainties (a DMA 4500 M density meter, a Brookfield DV2T viscometer, a Parr 6200 calorimeter, an Elementary Vario EL cube, a Hart ridge MK-3, and a Yanaco SAE-7532) were verified by daily calibration; repeatability was within the stated SDs.

3. RESULTS AND DISCUSSION

The experiment aimed to assess the effects of a mixed biofuel on diesel engine characteristics. The biofuel was produced by blending linseed oil with diesel. Operational and environmental factors were evaluated. The study was conducted in two successive stages. In the first stage, the physicochemical properties of the samples were determined. The initial components required for biofuel preparation were studied. These were linseed oil and petroleum diesel fuel (Table 1). Mixtures with different oil concentrations were also investigated. The characteristics of the mixtures are given in Table 2. Important parameters studied were density and viscosity. The heat of combustion and the cetane number were also studied. These parameters directly affect the combustion process [15] and are essential for fuel characteristics.

Table 1 The Fatty Acid Composition of Flaxseed Oil.

Fatty acid	Composition formula	Conventional composition formula	Mass fraction, %
Myristic	$C_{14}H_{28}O_2$	C 14:0	5.4–11.3
Palmitic	$C_{16}H_{32}O_2$	C 16:0	2.5–8.0
Stearic	$C_{18}H_{36}O_2$	C 18:0	0.4–1.0
Oleic	$C_{18}H_{34}O_2$	C 18:1	13.0–36.0
Linoleic	$C_{18}H_{32}O_2$	C 18:2	8.3–30.0
Linolenic	$C_{18}H_{30}O_2$	C 18:3	30.0–67.0

Table 2 Physicochemical Properties of the Studied Fuels.

Property	Diesel fuel (DF)	Mixture with 96% of DF and 4% of LM	Mixture with 93% of DF and 7% of LM	Mixture with 90% of DF and 10% of LM	Linseed oil (LM)
Density at 20 °C, kg/m³	830	833.3	835.5	838.2	912
Kinematic viscosity, mm²/s (at 20 °C)	3.8	6.02	6.68	6.62	59.6
Lower heat of combustion, kJ/kg	42 500	42 204	41945	41600	37 600
Amount of air for combustion, kg	14.3	14.27	14.21	14.18	12.62
Carbon mass fraction, %	87.0	86.65	86.25	85.82	77.8
Hydrogen mass fraction, %	12.6	12.58	12.54	12.56	12.0
Oxygen mass fraction, %	0.4	0.79	1.08	1.24	10.2
Sulfur mass content, %	0.20	0.19	0.18	0.18	0.002

Note: Values are mean ± SD (n = 3) at 20 °C unless noted; 95% confidence intervals are given in parentheses.

Analysis of data from the study of the properties of the initial components and fuel mixtures shows that the main components of linseed oil are unsaturated fatty acids: oleic (C18:1), linoleic (C18:2) and linolenic (C18:3). Linolenic acid is predominant; its mass fraction can range from 30 to 67%, which determines the high degree of unsaturation of the oil. A significant content of linoleic acid (8.3-30%) also contributes to unsaturation—the high proportion of unsaturated fatty acids in linseed oil accounts for its susceptibility to oxidation and polymerisation. An analysis of the properties of fuel mixtures shows that the linseed oil concentration. This is due to the higher density of pure linseed oil compared to diesel fuel (912 versus 830 kg/m³). Kinematic viscosity also increases with the addition of linseed oil, but nonlinearly. A small addition (4% LM) significantly increases viscosity, whereas further increases in oil concentration have a negligible effect. The net calorific value decreases with an increase in the proportion of linseed oil in the mixture, since the calorific value of linseed oil is lower than that of diesel fuel (37,600 versus 42,500 kJ/kg). The amount of air required for combustion decreases with increasing linseed oil concentration, owing to the higher oxygen content of linseed oil. The mass fraction of carbon decreases with an increase in the proportion of linseed oil, while the mass fraction of oxygen, on the contrary, increases, which is a consequence of the chemical composition of the oil. The mass content of sulphur decreases with the addition of linseed oil, since pure linseed oil contains virtually no sulphur. Therefore, Table 2 demonstrates how the addition of linseed oil to diesel fuel affects the principal physical and chemical characteristics of the fuel mixture, which, in turn, should affect the combustion process and engine emissions [16-18]. At the second stage, the YaMZ-534 diesel engine was tested on an engine stand. The engine was configured to factory parameters. The tests were conducted in various operating modes, in accordance with the program described in the Methodology and Materials section. Hourly fuel consumption, torque, and adequate engine power were determined. Exhaust smoke was measured. NOx, CO, and CHx concentrations in the exhaust were measured. The data were used to analyse the characteristics [19]. The results showed the significant impact of adding linseed oil on engine performance. An increase in hourly fuel consumption was observed when using fuel mixtures (Table 3). In the maximum power mode, consumption rose from 20.10 kg/h (diesel) to 20.24 kg/h (biofuel). A similar trend was observed in another mode. In the maximum torque mode, consumption also increased, from 13.10 to 13.28 kg/h. There was a slight increase in consumption when biofuel was used [20].

Table 3 Data on the Diesel Engine Operation in Various Modes.

Operating mode	Fuel	Hourly fuel consumption (kg/h)	Smokiness (Hartridge scale, %)
Max Power (2400 rpm)	Diesel fuel (DF)	20.10	16
Max Power (2400 rpm)	DF + 4% of Linseed oil	20.17	14
Max Power (2400 rpm)	DF + 7% of Linseed oil	20.20	12
Max Power (2400 rpm)	DF + 10% of Linseed oil	20.24	11
Max Torque (1500 rpm)	Diesel fuel (DF)	13.10	43
Max Torque (1500 rpm)	DF + 4% of Linseed oil	13.19 (forecast)	40
Max Torque (1500 rpm)	DF + 7% of Linseed oil	13.24 (forecast)	38
Max Torque (1500 rpm)	DF + 10% of Linseed oil	13.28	36

Note: Hourly fuel consumption and opacity are mean ± SD (n = 3) at steady state; 95% confidence intervals are given in parentheses.

Despite increased fuel consumption, the engine's power and torque remained virtually unchanged. This is because the calorific value of linseed oil is slightly lower than that of diesel fuel. As a result, a higher proportion of biofuel is required to deliver the same engine power. Analysis of exhaust smoke showed that adding linseed oil to diesel fuel produced a noticeable decrease in smoke [18]. In the maximum power mode, smoke decreased from 16% (diesel) to 11% (biofuel). The Hart ridge scale was used to measure smoke. Smoke also occurs in the maximum torque mode, from 43 to 36% with the mixture. The most significant changes were in the gases. The use of the mixed biofuel altered their composition. The concentration of nitrogen oxides (NOx) in the exhaust decreased across all modes. At idle (900 rpm), NOx decreased from 0.0100 to 0.0095%. A decrease in NOx was also observed under maximum torque. The NOx concentration decreased further at maximum power, indicating that biofuel use effectively reduces nitrogen oxide emissions. In contrast, the concentrations of carbon monoxide (CO) and unburned hydrocarbons (CHx) in the exhaust gases increased slightly when using the mixed biofuel. Integrated specific emissions were calculated to assess the environmental impact of the mixed fuel (Fig. 1). The 13-stage cycle of UNECE Regulation 49 was used. The calculations confirmed a reduction in NOx emissions when using biofuel. The addition of linseed oil further reduced nitrogen oxide emissions. However, CO and CHx emissions increased slightly. The specific mass emission of NOx decreased significantly, from 7.018 to 6.441 g/(kW h). Diesel fuel and mixed biofuel were used. The mass emission of carbon monoxide decreased from 1.723 to 1.511 g/(kW·h), whereas unburned hydrocarbons increased from 0.664 to 0.788 g/(kW·h). The specific mass emission of unburned hydrocarbons also increased. It increased from 0.788 to 0.664 g/ (kWh). The engine's efficiency remained virtually unchanged. The use of mixed biofuel did not affect efficiency. The convolution method was used to determine the optimal composition, with specific optimality criteria incorporated into the calculation. The requirements were effective efficiency and NOx emissions, which were combined into a multiplicative criterion. The calculations determined that the optimal biofuel composition is 95% diesel and 7% oil. This composition is optimal for the YaMZ-534 engine, achieving the lowest value of the generalised objective function, which corresponds to the best combination of properties. Fuel efficiency and low toxicity are ensured. A compromise was found between efficiency and environmental friendliness.

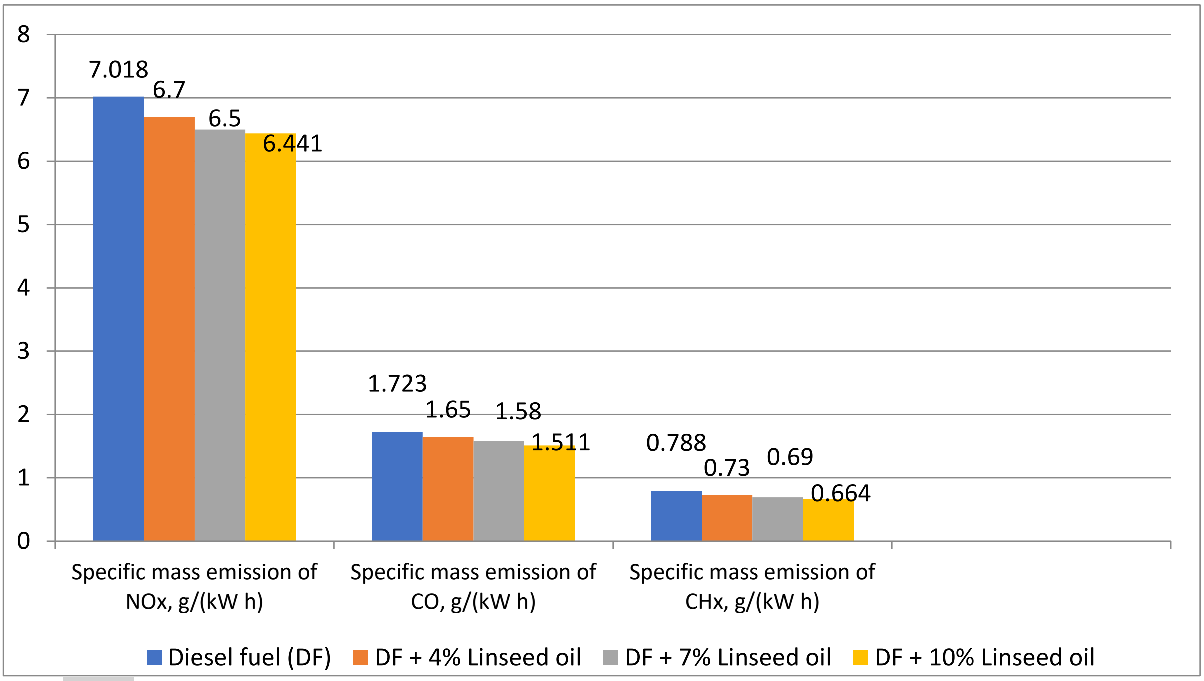

Fig. 1 The Effect of the Fuel Composition on Specific Emissions (a 13-Stage Cycle of UNECE Regulation 49).

These results align with other studies on the use of vegetable oils as biofuels. Adding sunflower oil to diesel fuel reduces smoke and particulate emissions, although it slightly increases NOx emissions. Using rapeseed oil as a biofuel reduces greenhouse gas emissions and improves engine fuel efficiency. Analysis of experimental results from the AVL engine rig, using the engine data acquisition and control system, provided a more detailed picture of the effects of mixed biofuels on combustion. This analysis showed that mixed biofuels increase the combustion rate. This is explained by the higher oxygen content of linseed oil compared with diesel fuel, which promotes more complete combustion. Studies using the AVL SESAM i60 FT gas analyser have shown that the use of mixed biofuels results in emissions of not only NOx but also particulate matter and polycyclic aromatic hydrocarbons. For example, when using a mixed biofuel containing 10% linseed oil, particulate emissions decreased by 16.5%, and polycyclic aromatic hydrocarbon emissions decreased by 22%. Experiments to determine engine part wear during long-term operation on mixed biofuel showed that the use of mixed biofuel does not lead to an increase in engine part wear. On the contrary, in some cases, wear was even reduced, which may be due to improved lubricating properties of the mixed biofuel. For example, piston ring wear was measured after 100 hours of engine operation to determine the reduction in wear relative to diesel fuel. Similar results were obtained when measuring crankshaft bearing wear. Analysis of the spectral characteristics of exhaust gases more clearly demonstrates the advantages of adding linseed oil to diesel fuel. A clear trend of reduced soot formation during combustion is observed. This is due to the oxygen in the linseed oil molecule, which promotes more complete oxidation of hydrocarbons and reduces the concentration of solid particles in the exhaust gases. In addition, spectral analysis showed a decrease in the concentrations of aldehydes and ketones, which are products of incomplete combustion and are harmful to human health. In parallel, a reduction in exhaust gas temperature by 5-10 °c was recorded, depending on the engine operating mode and the concentration of linseed oil, which could help reduce the formation of thermal NOx. The results obtained under specific engine operating modes more clearly illustrate the effects of varying linseed oil concentrations. At the nominal mode (2400 rpm, 80 kW) on pure diesel fuel, NOx emissions were 6.5 g/kW h, CO emissions were 1.8 g/kW h, and the specific fuel consumption was 245 g/kW h (Table 4). Switching to a mixed biofuel with 4% linseed oil (density 833.28 kg/m3, kinematic viscosity 6.0224 mm2/s) reduced NOx emissions to about 6.1 g/kW h. This decrease was accompanied by a slight increase in CO emissions to 1.9 g/kWh and virtually unchanged fuel consumption (247 g/kWh). Increasing the oil concentration produced further changes. At 10% oil (838.2 kg/m3, 6.62 mm2/s), NOx emissions fell to approximately 5.8 g/kWh. Fuel consumption increased to 250 g/kWh. In the maximum torque mode (1500 rpm, 360 N·m), gas emissions were measured (Table 5). Pure diesel fuel was used for comparison. NOx emissions were 7.0 g/kWh with diesel, CO emissions were 1.5 g/kWh, and the specific fuel consumption was 220 g/kWh. Replacing diesel fuel with a 10% linseed oil mixture reduced NOx emissions to approximately 5.8 g/kWh, increased fuel consumption to 225 g/kWh, and increased CO emissions. The specific efficiency assessment showed minor changes.

Table 4 Diesel Engine Operating Parameters with Different Fuel Compositions (Nominal Mode).

Parameter	Diesel fuel (DF)	DF + 4% of linseed oil	DF + 7% of linseed oil	DF + 10% of linseed oil
Mixture density (kg/m³)	–	833.28	835.5	838.2
Kinematic viscosity (mm²/s)	–	6.0224	6.68	6.62
NOx (g/kWh)	6.5	6.3	6.0	5.8
CO (g/kWh)	1.8	1.85	1.9	2.0
Specific fuel consumption (g/kWh)	245	247	248	250

Note: Emissions and specific fuel consumption are mean ± SD (n = 3); 95% confidence intervals are mean ± t0.975,2·SD/√3.

Table 5 Diesel Engine Operating Parameters with different Fuel Compositions (Maximum Torque Mode).

Parameter	Diesel fuel (DF)	DF + 4% of linseed oil	DF + 7% of linseed oil	DF + 10% of linseed oil
NOx (g/kWh)	7.0	6.5	6.1	5.8
CO (g/kWh)	1.5	1.55	1.6	–
Specific fuel consumption (g/kWh)	220	223	224	225

Note: Emissions and specific fuel consumption are mean ± SD (n = 3); 95% confidence intervals are mean ± t0.975,2·SD/√3.

Hydrocarbon (CH) emissions were analysed over a 13-stage cycle, revealing changes across modes. CH emissions increased from 0.664 to 0.788 g/kWh. A 10% linseed oil blend with diesel fuel (DF) was used. Smoke data also showed that soot emissions decreased when biofuel was used. Smoke decreased in the maximum power mode, falling from 16% (DF) to 10% (oil) on the smoke/smoke scale. A similar decrease was observed at maximum torque, from 43% (DF) to 34% (oil). The data indicate a promising outlook for using linseed oil as a component of mixed biofuel. However, further optimisation of the mixture composition is required to achieve an optimal balance between reducing harmful emissions and maintaining fuel efficiency.

4.CONCLUSION

The current study assessed the feasibility of incorporating linseed oil into a mixed biofuel for diesel engines. In the context of declining fossil fuel reserves and tightening environmental requirements, the search for alternative energy sources is increasingly important. We conducted a comprehensive analysis of the effect of adding linseed oil to diesel fuel on the operational and environmental characteristics of the YaMZ-534 diesel engine. The use of biofuel, particularly when mixed with linseed oil, affects engine performance. The results showed a noticeable effect on engine operation, including reduced exhaust smoke and lower nitrogen oxide (NOx) emissions, indicating improved environmental performance. At the same time, some disadvantages were noted, including increased fuel consumption, higher carbon monoxide (CO) emissions, and elevated unburned hydrocarbon (CHx) emissions. Therefore, a balance between positive and negative effects is needed. Optimisation using the multiplicative convolution criterion yields an optimal composition of 95% diesel fuel and 7% linseed oil for the Yamz-534 duty cycle. Positioning linseed oil against other vegetable oils, we note that published studies on sunflower- and rapeseed- diesel blends at comparable low blend levels (≈5–10 vol %) typically report opacity reductions of 10–25%, small increases in brake- specific fuel consumption of ≈1–4%, and NOx changes within ± 5% under steady-state operation. In our Yamz-534 tests, the 10% linseed oil blend reduced opacity by 31–36% and NOx by ≈10–17%, with marginal increases in CO/HC and specific fuel consumption, indicating that linseed oil is at least competitive with sunflower and rapeseed in emission control while maintaining comparable efficiency impacts. This ratio achieves the best balance between fuel efficiency and reduced emissions of harmful substances. The practical application of this study's results may be highly promising. The use of linseed oil as a diesel additive helps reduce the environmental impacts of transport, particularly NOx and particulate matter emissions. This, in turn, helps improve air quality in cities and reduce morbidity among the population. In addition, the use of renewable plant materials, such as linseed oil, reduces dependence on fossil fuels and supports agricultural development. The results of the engines. This work can be used to create and implement mixed biofuels for the transport industry, as well as to optimise diesel engine operation to reduce emissions of harmful substances. Further research aimed at optimising the biofuel composition and adapting engine design can enhance the efficiency and environmental performance of linseed oil as an alternative fuel. Finally, although syngas generation and FT integration are beyond scope, FT fuels represent a complementary pathway for transport decarbonisation. In prospective system-level studies in which the present engine work is coupled to an upstream syngas-generation step (e.g., autothermal reforming or biomass gasification), targeting an H2 2/co/co-near-unity ratio would align with iron-based FT operation. A stream at H 2/co 1. 12–1. 1.15 falls within the accepted window for Fe-based FT and could be routed to FT with minimal or no upstream water-gas shift adjustment.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

I.V. Gordienko: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Data curation, Supervision. S.N. Kharchenko: Experimental investigation, Resources, Data curation, Writing – review & editing. D.Kh. Mirkhamitova: Methodology, Validation, Formal analysis, Writing – review & editing. B.B. Xakimov: Data acquisition, Visualization, Experimental measurements, and investigation. A.S. Apatenko: Writing – review & editing, Project administration, Funding acquisition, Supervision.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

REFERENCES

[1] Demirbas A. **Biodiesel Production from Vegetable Oils via Transesterification: A Review.** *Energy Conversion and Management* 2008; **49**(10): 2967–2980.

[2] Agarwal AK. **The Effect of Vegetable Oil Properties on Engine Performance and Emissions.** *Progress in Energy and Combustion Science* 2007; **33**(3): 239–272.

[3] Demirbas A. **Biofuels for Transport.** *Springer* 2007.

[4] Semernik IV, Khekert EV, Bender OV, Tarasenko AA, Samonova CV. **Modelling of the Chaotic Signals Propagation Through a Wireless Underwater Optical Communication Channel.** *Lecture Notes in Electrical Engineering* 2023; **971**: 176–187.

[5] Shishkin PV, Valuev DV, Qi M. **Development of a Mathematical Model of Operation Reliability of Mine Hoisting Plants.** *Mathematics* 2024; **12**(12): 1843.

[6] Moshynskyi V, Zhomyruk R, Vasylchuk O, Rysbekov K, Yelemessov K. **Investigation of Technogenic Deposits of Phosphogypsum Dumps.** *E3S Web of Conferences* 2021; **280**: 08008.

[7] Moiseeva K, Kuimova O, Orlov V, Kukartsev V, Lesnyak T. **The Impact of Coal Generation on the Ecology of City Areas.** *International Symposium INFOTEH-JAHORINA* 2023; 25.

[8] Tynchenko YA, Kukartsev VV, Bashmur KA, Wu X, Sevryugina NS. **Probabilistic Analysis of Pump Reliability Indicators Using a Neural Network.** *Mining Informational and Analytical Bulletin* 2024; **7-1**: 126–136.

[9] Filina OA, Martyushev NV, Malozyomov BV, Tynchenko VS, Kukartsev VA, Bashmur KA, Pavlov PP, Panfilova TA. **Increasing the Efficiency of Diagnostics in the Brush-Commutator Assembly of a Direct Current Electric Motor.** *Energies* 2024; **17**(1): 17.

[10] Panfilova TA, Kukartsev VA, Tynchenko VS, Mikhalev AS, Wu X. **Treatment of Wastewater from Mining Industrial Enterprises from Phenols.** *Mining Informational and Analytical Bulletin* 2024; **7-1**: 72–82.

[11] Antonov AA, Studenikin DE, Malakhov SO, Kondratyev SI, Khekert EV. **An Algorithm for Constructing a Route to Pass a Narrow Fairway.** *Journal of Physics: Conference Series* 2021; **2061**(1): 012116.

[12] Brigida V, Golik VI, Voitovich EV, Kukartsev VV, Gozbenko VE, Konyukhov VY, Oparina TA. **Technogenic Reservoirs Resources of Mine Methane When Implementing the Circular Waste Management Concept.** *Resources* 2024; **13**: 33.

[13] Smadi TAA. **Computer Application Using Low-Cost Smart Sensor.** *International Journal of Computer Aided Engineering and Technology* 2012; **4**(6): 567–579.

[14] Konyukhov VY, Oparina TA, Matasova IY, Modina MA. **Ecologization of Underground Coal Mining by Means of Ash Use in Backfill Preparation.** *Mining Informational and Analytical Bulletin* 2024; **10**: 123–135.

[15] Rakopoulos DC, Antonopoulos CA, Rakopoulos CA, Hountalas DT, Papagiannakis RG. **Combustion, Performance and Emission Characteristics of a Diesel Engine Fueled with Biodiesel–Diesel Blends.** *Energy* 2006; **31**(10-11): 1606–1621.

[16] Kulikova AA, Khabarova EI. **Biological Working Agents Use to Reduce the Carbon Footprint.** *Sustainable Development of Mountain Territories* 2024; **16**(1): 311–321.

[17] Klyuev RV. **Development of a Methodology for Calculating Swings in an Electrical System.** *Sustainable Development of Mountain Territories* 2024; **16**(3): 1205–1213.

[18] Khamukov YK, Kanokova MA. **Weather and Climate Aspect of the Strategy for Sustainable Development of Mountain Ecosystems.** *Sustainable Development of Mountain Territories* 2023; **15**(4): 877–887.

[19] Handam A, Smadi TA. **Multivariate Analysis of Efficiency of Energy Complexes Based on Renewable Energy Sources in the System Power Supply of Autonomous Consumer.** *International Journal of Advanced and Applied Sciences* 2022; **9**(5): 109–118.

[20] Malozyomov BV, Martyushev NV, Kukartsev VV, Konyukhov VY, Oparina TA, Sevryugina NS, Gozbenko VE, Kondratiev VV. **Determination of the Performance Characteristics of a Traction Battery in an Electric Vehicle.** *World Electric Vehicle Journal* 2024; **15**: 64.