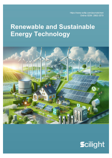
Scilight

Renewable and Sustainable Energy Technology

https://www.sciltp.com/journals/rset



Article

Low-Carbon Alternative Fuels Toward Sustainable Mobility: Biodiesel Production and Comparative Analysis of Its Blends with Diesel

Tamer M. M. Abdellatief [1,2,*], Khuloud Almesafri [3] and Leen Al-Marzuqi [3]

[1] Sustainable Energy & Power Systems Research Centre, Research Institute of Sciences and Engineering (RISE), University of Sharjah, Sharjah P.O. Box 27272, United Arab Emirates
[2] Department of Chemical Engineering, Faculty of Engineering, Minia University, EL-Minia 61519, Egypt
[3] Department of Sustainable and Renewable Energy Engineering, College of Engineering, University of Sharjah, Sharjah P.O. Box 27272, United Arab Emirates
* Correspondence: tamerabdellatief@mu.edu.eg

How To Cite: Abdellatief, T.M.M.; Almesafri, K.; Al-Marzuqi, L. Low-Carbon Alternative Fuels Toward Sustainable Mobility: Biodiesel Production and Comparative Analysis of Its Blends with Diesel. *Renewable and Sustainable Energy Technology* **2026**, *2*(2), 9. https://doi.org/10.53941/rset.2026.100006

Received: 23 February 2026
Revised: 19 June 2026
Accepted: 23 June 2026
Published: 26 June 2026

Abstract: The current work seeks to explore the viability of generating biodiesel from waste cooking oil as an economically viable waste biomass through the transesterification process and studied different blends with petroleum diesel (B0 to B100). Key fuel characteristics, such as cetane number, acid value, density, calorific value, flash point, and viscosity, were measured. The findings reported that the cetane number slightly increases as biodiesel is mixed with the blend. Moreover, the heating value gradually drops as biodiesel is mixed with diesel: 44.01 MJ/kg for B5, 43.59 MJ/kg for B10, 42.81 MJ/kg for B20, 42.53 MJ/kg for B25, 42.61 MJ/kg for B30, 41.81 MJ/kg for B40, 41.52 MJ/kg for B50, and 39.49 MJ/kg for pure biodiesel (B100). When compared with neat diesel, neat biodiesel indicated a cumulative decrease of approximately 11.4%. The biodiesel's good quality was confirmed by the gradual drop in sulfur content, which helped to reduce possible emissions, and the total glycerol, which stayed well below standard limits. It was discovered that low to medium blends (B5–B20) provide better combustion and environmental performance while being completely compatible with traditional diesel engines without the need for modification. Although higher blends (B40–B100) have better safety and pollution benefits, their increased viscosity and lower energy content may necessitate slight modifications to engine calibration or fuel injection. Finally, this study reported that biodiesel–diesel blends are a viable, sustainable, and eco-friendly way to lessen dependency on fossil fuels while preserving engine performance. It also offers important information for maximizing blend ratios for emissions compliance and performance.

Keywords: biodiesel; renewable diesel; cetane number; calorific value; biodiesel-diesel blends; glycerol

1. Introduction

The most crucial component of social and economic advancement for raising living standards is energy. The majority of the world's energy sources now come from fossil fuels, which will eventually run out if we don't create systems that can use other fuels to generate energy [1]. Global energy demand is increasing at a higher rate than population growth. Due to the high energy consumption of developing nations, particularly those in Asia, this increment projection is predicted to rise by up to 1.5% by 2030 [2]. According to some linked studies, the world's largest fuel exporters are compelled by the growing need for energy to find alternative fuels so that they can stop relying on fossil fuel-based products. Since sustainability is one of the primary challenges preventing the energy sector from reaching its full potential, all stakeholders—including government entities, private industries, corporations, nongovernmental organizations, academic institutions, and individuals—must actively support the development and utilization of innovative and renewable energy resources.

Except for hydroelectricity and nuclear energy, the majority of the world's energy demands are met by petrochemical, coal, and natural gas sources; all of these are limited and will soon be depleted at current rates of use [1]. Diesel fuels are vital to a developing nation's industrial economy since they are used to run diesel tractors and pump sets in the agriculture sector, as well as to carry industrial and agricultural goods [3,4]. There is usually a corresponding rise in transportation when the economy grows. The development of renewable energy sources with a limitless lifespan and a lower environmental impact than conventional ones is becoming more and more important due to the high energy demand in both the domestic and industrialized worlds, as well as the pollution issues brought on by the widespread use of fossil fuels [5]. This has recently attracted attention to fossil fuel surrogates. Economic competitiveness, availability, environmental acceptability, and technical viability are all key necessities for surrogate fuels [6]. The use of renewable plant oils, like woody plant oilseeds and vegetable oils, can serve as alternatives to petroleum-based fuel [7]. This surrogate diesel fuel is identified as biodiesel or biomass-derived diesel fuel [8,9].

Biodiesel is a renewable and biodegradable alternative to conventional diesel fuel [10,11]. It is mainly made from vegetable oils, animal fats, or waste cooking oils through a chemical process called transesterification. Comprising fatty acid methyl esters, biodiesel is chemically dissimilar to diesel derived from traditional crude oil; however, it can be used with traditional diesel engines in both pure and blended configurations [4,12,13]. Several biodiesel–diesel mixture ratios are widely available, like B5, B20, B30, and B100 [14,15]. It can be utilized in traditional compression-ignition engines without notable modifications [16–18]. The ecological merits of petroleum diesel additives and renewable-based diesel are maximized through promotive policy and infrastructure advancement [19,20]. Furthermore, Life cycle assessments (LCA) illustrated that utilizing bio-based diesel fuel, particularly from algae or waste oils, reduces the carbon footprint in industry and transport activities [21].

Tibesigwa et al. [22] forecasted that the logistics and transportation industry's deployment of B20 and B10 mixtures will result in significant reductions in carbon dioxide tailpipe emissions and energy utilization. Additionally, the feasibility of utilizing biodiesel mixtures in substitution for conventional diesel was further demonstrated by Gautam and Kumar's research [23], which highlighted that the ecological merits outweigh the performance drawbacks.

The transesterification process is widely established for generating biodiesel from used cooking oil, attaining yields surpassing 90% [24,25]. Accordingly, used cooking oil plays a role as a biodiesel raw material with well-established technological readiness and ecological merits [26–28]. UCO is transformed into biodiesel, which is considered a potential surrogate for petroleum diesel [29,30].

The current work seeks to explore the viability of generating biodiesel from waste cooking oil as an economically viable waste biomass through the transesterification process and to study different blends with petroleum diesel (B0 to B100). Key fuel characteristics, such as cetane number, acid value, density, calorific value, flash point, and viscosity, will be measured. Furthermore, the current study reported that biodiesel–diesel blends are a viable, sustainable, and eco-friendly way to lessen dependency on fossil fuels while preserving engine performance. It also offers important information for maximizing blend ratios for emissions compliance and performance.

2. Research Methodology

Used cooking oil collected from the University of Sharjah's dining facilities, methyl alcohol, and sodium hydroxide were the components used in the current study to generate biodiesel. Figure 1 shows the materials used for transforming used cooking oil to biodiesel. Ecological merits, affordability, and accessibility in waste valorization were the key reasons for employing UCO as the feedstock to generate biodiesel. Using sodium hydroxide, an alkaline medium catalyst, triglycerides in waste cooking oil were rapidly transformed into glycerol biodiesel [31].

Schematic illustration of the conversion of used cooking oil to biodiesel is depicted in Figure 2. Used cooking oil is the key raw material employed throughout the process [28]. The existence of water and impurities could negatively impact the transesterification reaction and reduce biodiesel generation; hence, appropriate pre-treatment is essential [32]. Following refining, the oil moves on to the transesterification phase, which is the main chemical process used to make biodiesel. Methanol is added as the alcohol reagent in this stage, and a catalyst—usually sodium hydroxide, or NaOH—is added to speed up the process. Triglycerides in used cooking oil are combined with methanol to produce fatty acid methyl esters (FAME), which make up biodiesel, and glycerol as a byproduct when heated to a regulated temperature and constantly stirred. Triglyceride molecules are broken down into smaller ester molecules by the process, which improves fuel qualities for diesel engines and lowers viscosity.

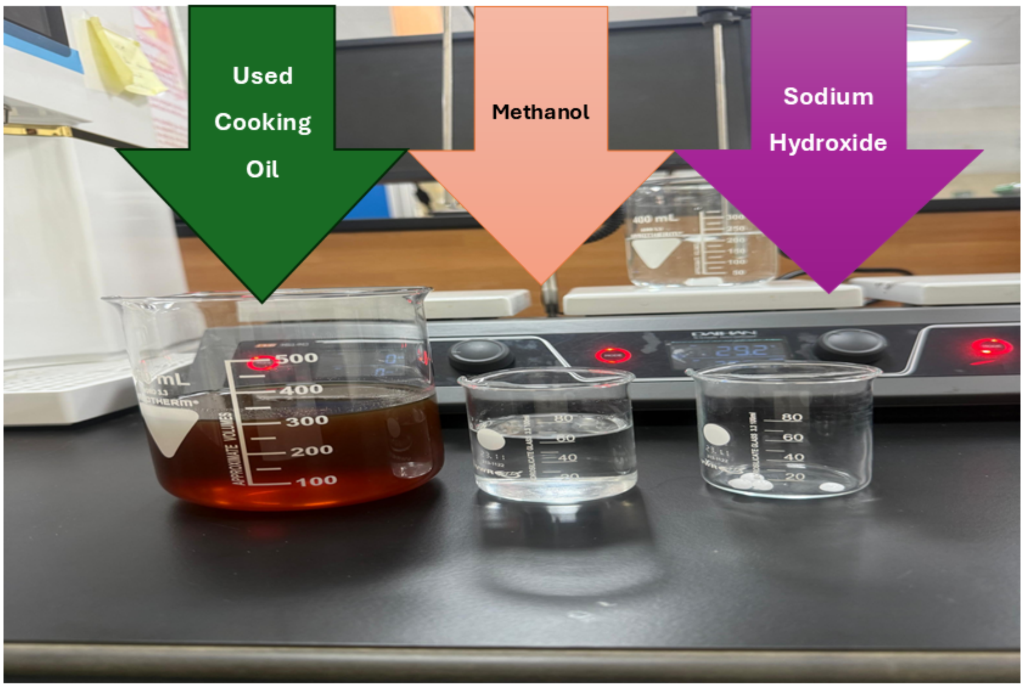


Figure 1. Materials used for transforming used cooking oil to biodiesel.

The mixture is allowed to settle after the reaction, which causes phase separation because of variations in density. Because it is heavier, glycerol sinks to the bottom, while biodiesel (FAME) forms the top layer. After removing the glycerol layer, crude biodiesel remains with contaminants, soap, catalyst, and leftover methanol. Figure 3 illustrates the Steps of the biodiesel reaction and separation of glycerol. The crude biodiesel is then cleaned with water in the following step to get rid of any remaining catalyst, extra methanol, and trace impurities. In addition to preventing engine-related problems like corrosion or injector deposits, proper washing guarantees adherence to fuel quality regulations [33]. Used cooking oil (UCO) was converted into biodiesel using an alkali-catalyzed transesterification process. Each batch involved a 6:1 methanol-to-oil molar ratio reaction between 1000 mL of filtered and warmed UCO and methanol. As the catalyst, 1 weight percent of sodium hydroxide (NaOH) was added to the oil volume. The transesterification reaction was continuously stirred at 600 rpm for 60 min at 60 °C.

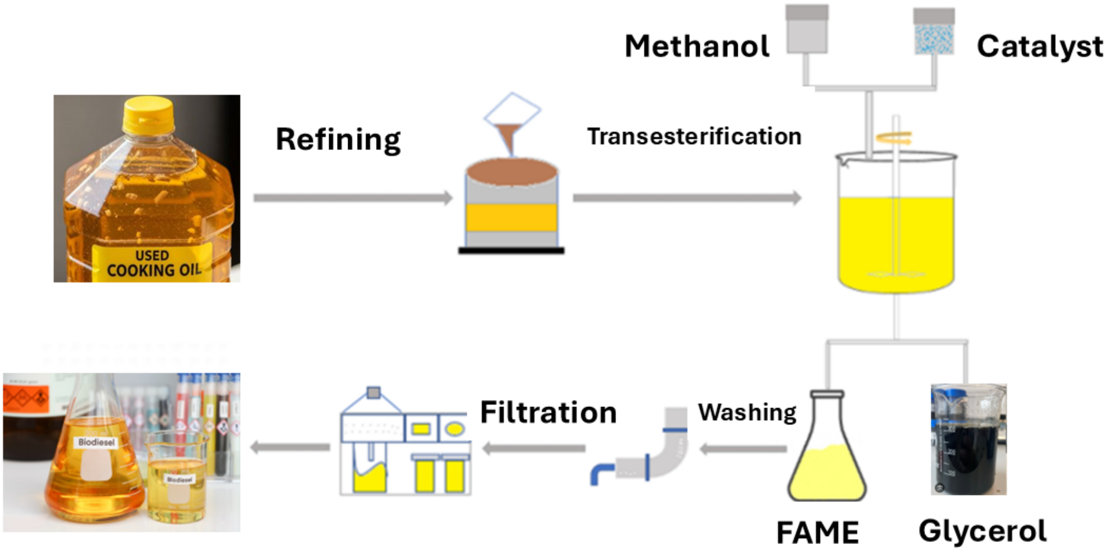


Figure 2. Schematic illustration of the conversion of used cooking oil to biodiesel.

Figure 4 presents the schematic presentation of the three stages of the biodiesel washing cycle. This last stage of purification yields clear, premium biodiesel that can be blended with petroleum fuel or characterized. Finally, the procedure supports waste valorization, emission reduction, and the shift to renewable energy sources by reducing environmental pollution caused by inappropriate disposal of used cooking oil and helping to produce a cleaner-burning, more sustainable substitute for traditional petroleum diesel.

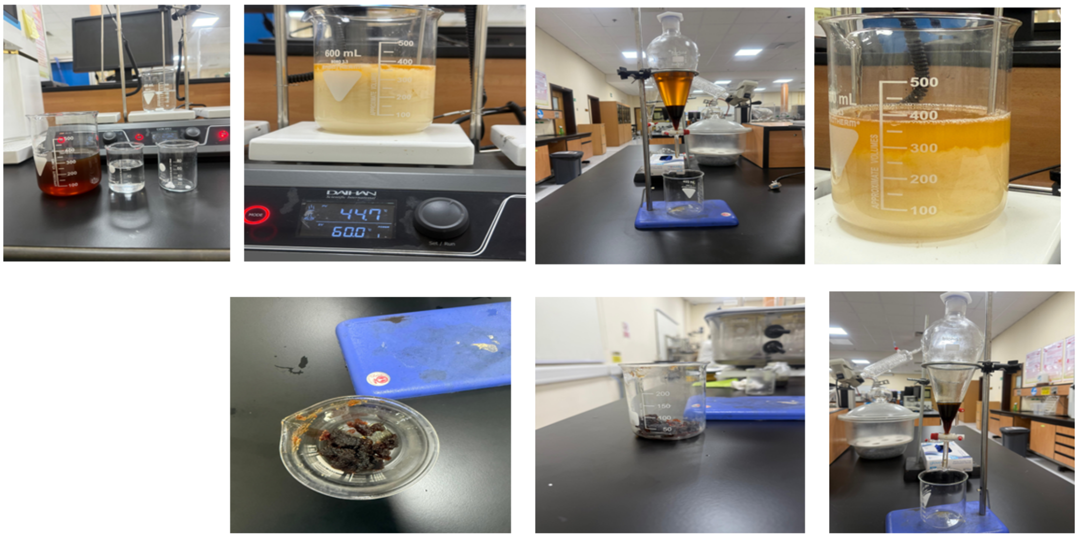


Figure 3. Steps of the biodiesel reaction and separation of glycerol.

Figure 4. Schematic presentation of the three stages of the biodiesel washing cycle.

3. Results and Discussion

3.1. Biodiesel Production and Its Characteristics

Table 1 and Figure 5 exhibit the influence of temperature on the kinematic viscosity (cP) of biodiesel, including the speed and accuracy. Viscosity gradually drops with increasing temperature, reaching 4.98 cP at 60.5 °C, or about a threefold decrease across the studied temperature range.

Table 1. Kinematic viscosity measurement results of the generated biodiesel based on UCO.

Viscosity (cp)	Temperature (°C)	Speed (rpm)	Accuracy
13.56	20.01	40	0.15 cp
12.13	24.90	40	0.15 cp
10.44	30.00	40	0.15 cp
9.04	35.00	40	0.15 cp
7.91	39.60	40	0.15 cp
7.00	44.80	40	0.15 cp
6.24	49.90	40	0.15 cp
5.56	54.70	40	0.15 cp
4.98	60.50	40	0.15 cp

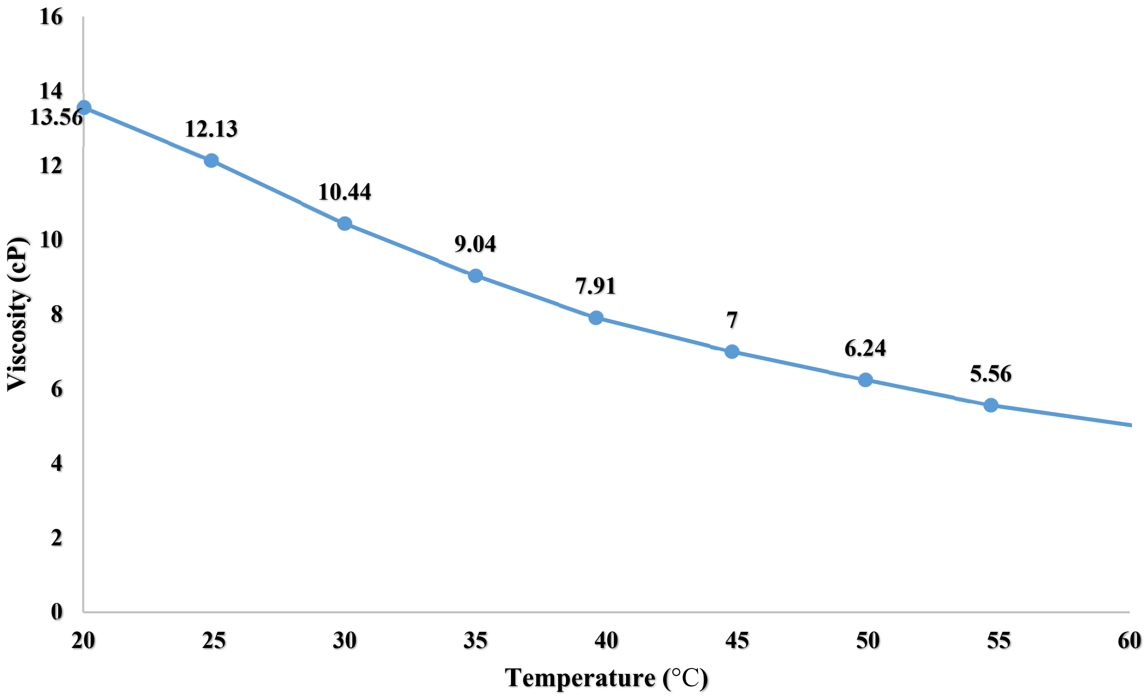


Figure 5. Impact of different ranges of temperature on the kinematic viscosity (cP) for biodiesel.

Figure 6 illustrates the distillation range curve of the biodiesel sample. The absence of light volatile hydrocarbons is shown by the Initial Boiling Point (IBP) of 290 °C, which is in line with the chemical makeup of biodiesel made primarily of fatty acid methyl esters (FAME). Biodiesel has a somewhat higher initial distillation temperature than petroleum diesel because it lacks low-boiling paraffinic or aromatic components. A homogeneous mixture dominated by C16–C18 methyl esters is characterized by a relatively limited and smooth distillation range, which is demonstrated by the steady and progressive temperature increase from T5 (297 °C) to T95 (397 °C).

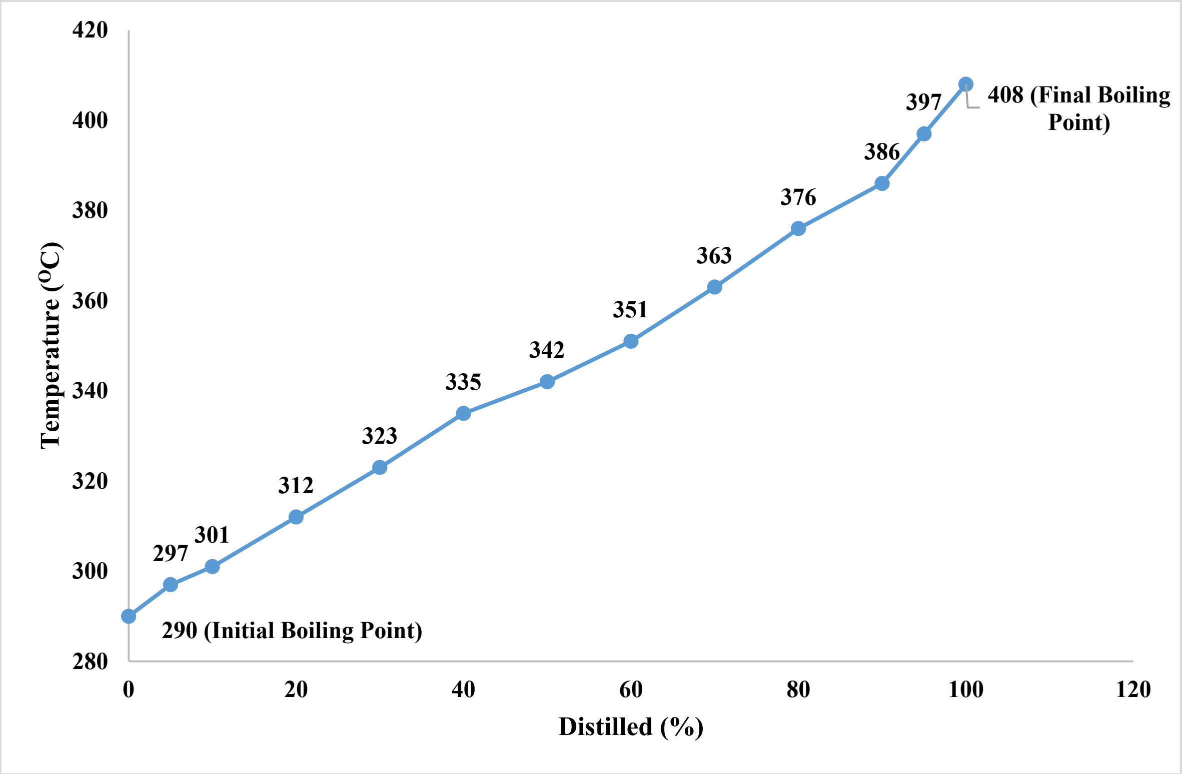


Figure 6. Distillation range curve of biodiesel sample.

Great fuel consistency and few impurities from volatile fractions, including leftover alcohol or overly heavy molecules, such as unreacted triglycerides or polymerized ingredients, are reported by this smooth volatility curve. The absence of high-boiling residues that can cause deposit formation, injector fouling, or incomplete combustion is highlighted by the FBP of 408 °C, which is notably lower than the designated ultimate limit of 420 °C.

3.2. Biodiesel-Diesel Blends Characterizations

As the percentage of biodiesel in the blend increases from B0 to B100, the density values shown in Figure 7 clearly indicate a steady and continuous increase. Pure fossil diesel (B0) exhibits a density of 832 kg/m^3 at 15 °C, while pure biodiesel (B100) reaches 889.3 kg/m^3, indicating an overall increase of approximately 6.9% across the full blending spectrum. The near-linear growth from B5 (838 kg/m^3) to B50 (872 kg/m^3) indicates consistent blend formation without phase separation and high miscibility between biodiesel and diesel fuel. The density stays around standard diesel standards for lower blends (B5–B20), indicating no effect on engine hardware and calibration. Higher blending ratios (B40–B100), however, may cause changes in injection timing and spray dynamics due to the increased density, which could have an impact on fuel consumption and emission formation.

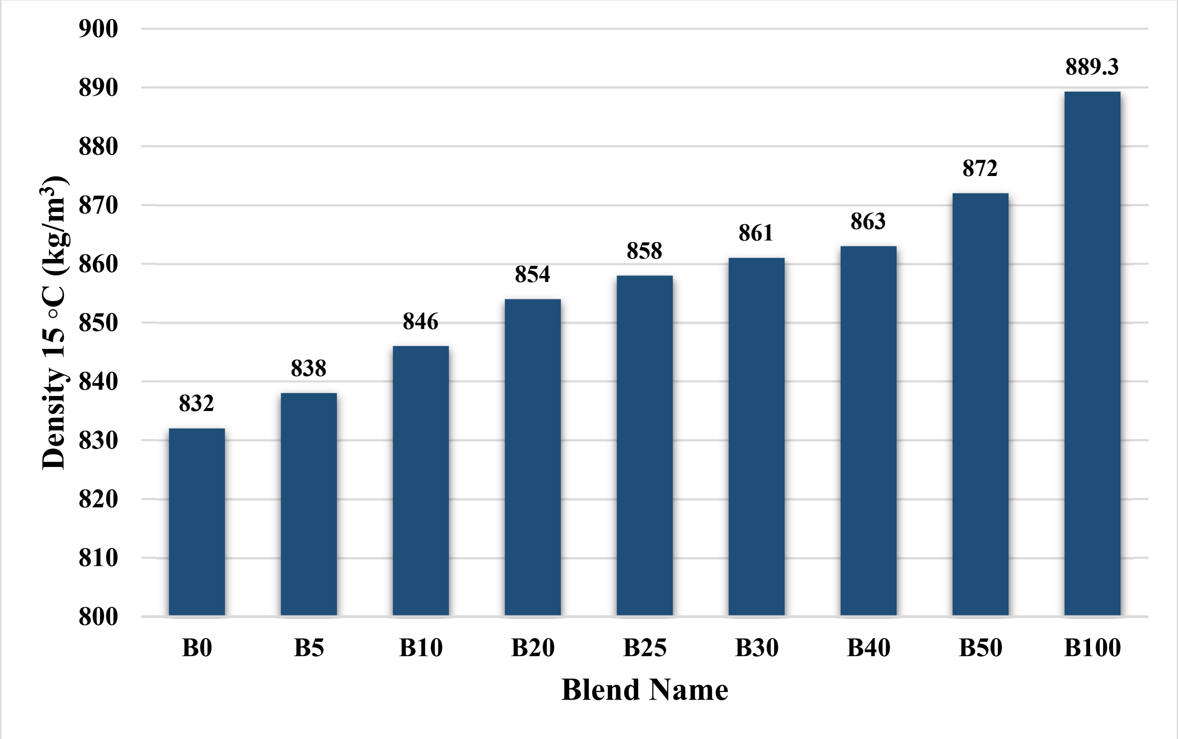


Figure 7. Influence of fuel density on several biodiesel-diesel mixtures.

Figure 8 illustrates the variations in kinematic viscosity of various biodiesel-diesel blends. In the diesel–biodiesel blends, the kinematic viscosity values at 40 °C clearly show a general increasing trend with higher biodiesel percentage. Due to its lighter hydrocarbon content and lack of oxygenated functional groups, pure fossil diesel (B0) exhibits a comparatively low viscosity of 2.53 mm^2/s, which is typical of petroleum diesel. The influence of fatty acid methyl esters (FAME), which have a larger molecular weight and stronger intermolecular interactions than diesel hydrocarbons, is seen in the viscosity, which progressively increases as the biodiesel fraction increases, reaching 2.72 mm^2/s for B5 and 2.87 mm^2/s for B10. With B20 at 3.29 mm^2/s and B30 at 3.46 mm^2/s, the viscosity keeps rising for higher mixes, demonstrating the biodiesel's increasing contribution to the blend's flow resistance. Despite a little deviance at B25 (3.04 mm^2/s), the general pattern is in line with the anticipated increasing trend. More than three times the viscosity of fossil diesel, the rise becomes more noticeable at increasing blending ratios, reaching 4.29 mm^2/s for B50 and a notable 8.90 mm^2/s for pure biodiesel (B100).

Fuels with extremely low viscosities might impair lubrication and cause leaks in injection pumps. According to ASTM D975 and EN 590 limitations of roughly 2.0 to 4.5 mm^2/s, the measured values for low and medium blends (B5–B30) are within the common diesel fuel requirements, suggesting satisfactory compatibility with traditional diesel engines without the need for changes. B100's high viscosity (8.90 mm^2/s) surpasses typical diesel standards, though, and may necessitate engine modifications or fuel preheating for best results.

As the amount of biodiesel in the blends increases, the flash point values in Figure 9 clearly and significantly rise. Because pure fossil diesel (B0) contains lighter and more volatile hydrocarbon fractions, it has a flash point of 60 °C, which is typical for standard petroleum diesel. The flash point gradually rises as the percentage of biodiesel increases: 70 °C (B5), 80 °C (B10), 100 °C (B20), 105 °C (B25), 115 °C (B30), 120 °C (B40), 130 °C (B50), and a significantly higher value of 185 °C for pure biodiesel (B100). This steady increase demonstrates how biodiesel greatly improves the blended fuel's thermal safety properties.

A notable improvement in fuel safety features is indicated by the notable increase from 60 °C (B0) to 185 °C (B100). According to various international fuel regulations, even mild blends like B20–B30 already have flash values of 100 °C, which is significantly greater than what is needed for traditional diesel.

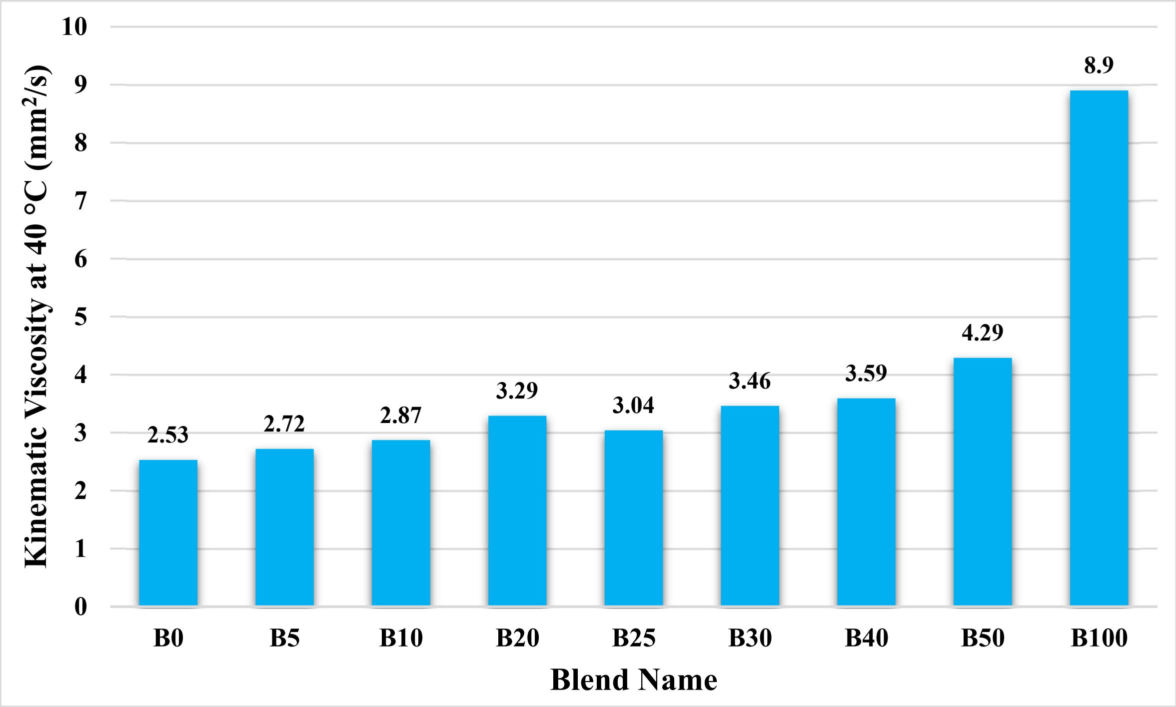


Figure 8. Influence of kinematic viscosity on several biodiesel-diesel mixtures.

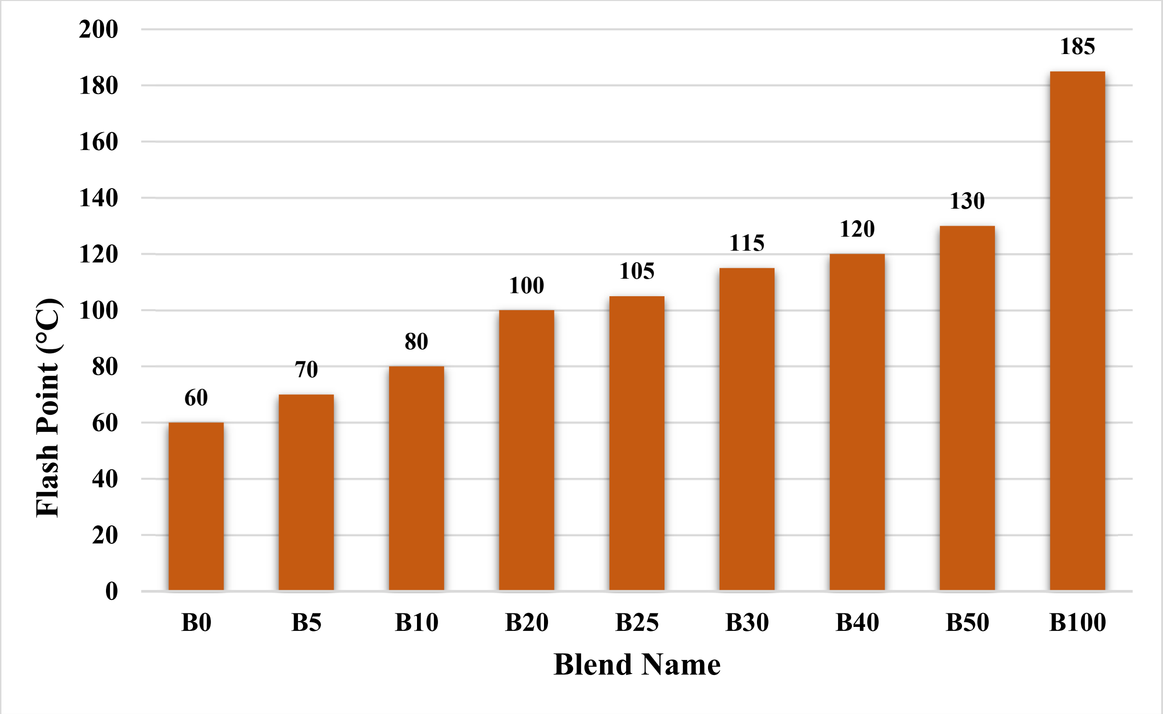


Figure 9. Impact of flash point of several biodiesel-diesel blends.

According to worldwide diesel fuel standards like ASTM D975 and EN 590, conventional diesel engines typically run well on fuels with cetane numbers between 40 and 55. Shorter ignition delays, smoother combustion, better cold-start behavior, and less engine banging are all linked to higher cetane levels. As the percentage of biodiesel in the diesel–biodiesel blends rises, the cetane number (CN) values illustrated in Figure 10 show a progressive improvement in ignition quality. The cetane value of 48 for pure fossil diesel (B0) is within the normal range for standard diesel fuels. The cetane number slightly increases as biodiesel is incorporated into the mixture; it is 49 for B5, 50 for B10, 52 for B20–B25, 53 for B30–B40, and 54 for neat biodiesel.

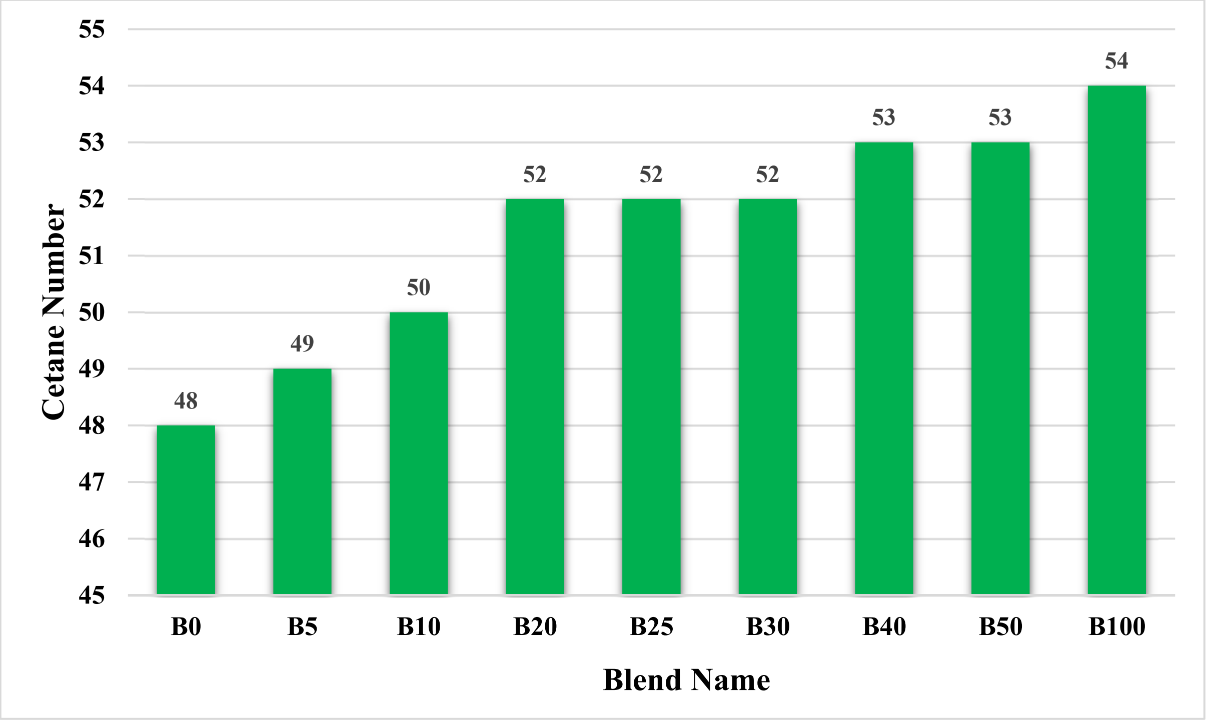


Figure 10. Influence of cetane number of several biodiesel-diesel mixtures.

Greater mixtures (B30–B100) generate notable enhancements in ignition quality, whereas intermediate blends (B5–B20) offer only marginal enhancement. This could enable engines to run more effectively and emit fewer emissions even in the absence of modifications. Figure 11 exhibits the variations in the heating value of various biodiesel-diesel blends. As the percentage of biodiesel in the fuel blend rises, the calorific energy content gradually decreases, according to the heating value table. Because petroleum hydrocarbons have a high energy density, pure fossil diesel (B0) has the maximum heating value, 44.53 MJ/kg. The heating value gradually drops as biodiesel is mixed with diesel: 44.01 MJ/kg for B5, 43.59 MJ/kg for B10, 42.81 MJ/kg for B20, 42.53 MJ/kg for B25, 42.61 MJ/kg for B30, 41.81 MJ/kg for B40, 41.52 MJ/kg for B50, and 39.49 MJ/kg for pure biodiesel (B100). Compared to pure diesel, this indicates an overall decrease of about 11.4% in pure biodiesel. The chemical makeup of biodiesel is the cause of the drop in heating value. When compared to hydrocarbon-rich fossil diesel, the net energy released per unit mass of fatty acid methyl esters (FAME) is lower due to the presence of oxygen atoms in their chemical structure. Furthermore, a greater percentage of long-chain fatty acids—which, in spite of their greater mass, release marginally less energy after combustion than petroleum hydrocarbons of the same mass—are found in biodiesel. Therefore, the total energy content per kilogram of fuel falls as the biodiesel fraction rises. Fuel consumption is impacted by the decrease in heating value from the standpoint of engine performance. Brake-specific fuel consumption (BSFC) may increase at higher blend ratios because engines may need slightly larger fuel volumes to achieve the same power output, because biodiesel blends provide less energy per unit mass. For low and medium blends (B5–B20), the impact is less severe, with a negligible decrease in heating value. Pure biodiesel (B100) and high mixes (B50 and above) exhibit a more noticeable decline, which can call for greater fuel flow or modifications to fuel injection to preserve engine performance. Although biodiesel and its blends have a lower energy content, they have other benefits such as a greater cetane number, fewer CO and unburned hydrocarbon emissions, better lubrication, and higher flash points. As a result, gains in combustion quality, engine dependability, and environmental performance outweigh the trade-off of a decreasing heating value as the amount of biodiesel increases. Furthermore, the data showed how crucial it is to balance the amount of biodiesel in blends to maximize energy efficiency and environmentally friendly engine running.

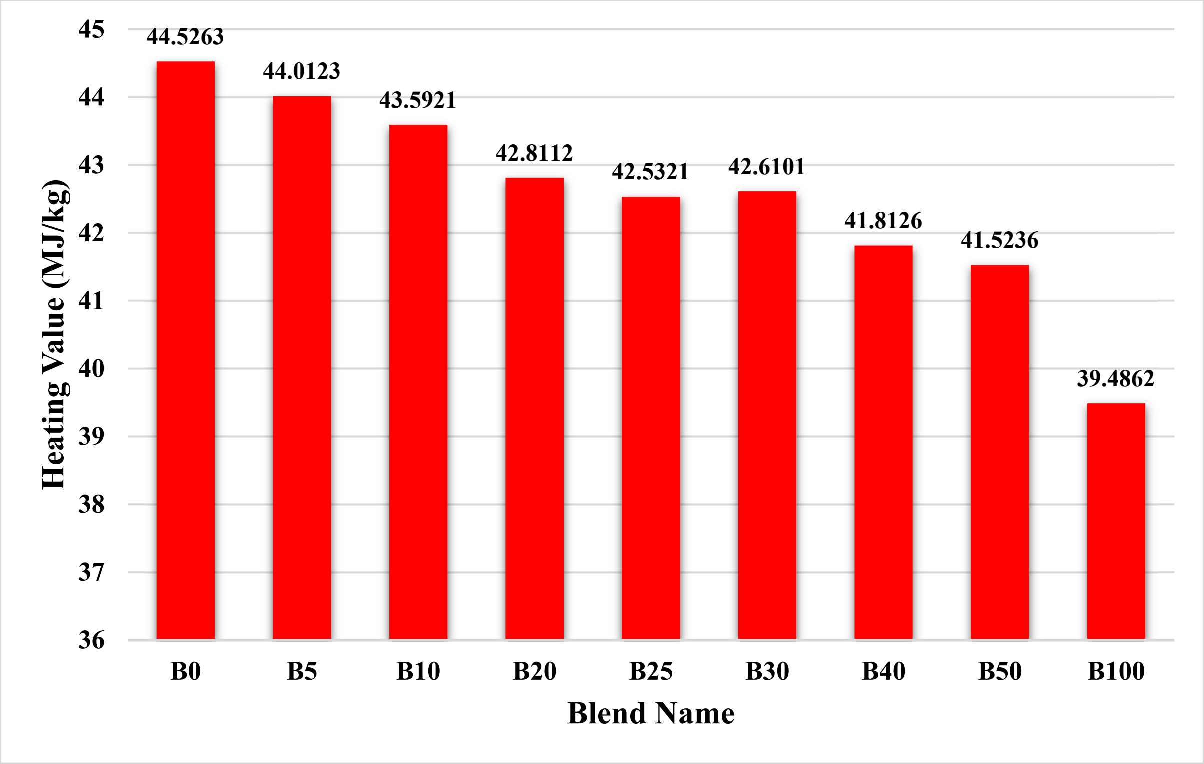


Figure 11. Variations in the heating value of various biodiesel-diesel blends.

As the percentage of biodiesel in the diesel–biodiesel blends rises, the sulfur content in Figure 12 demonstrates a progressive drop in sulfur concentration. The sulfur content of pure fossil diesel (B0) is 12 parts per million, which is already extremely low and reflects current ultra-low sulfur diesel regulations. The sulfur level marginally drops with the introduction of biodiesel: 11 ppm for B5, 10 ppm for B10, 9 ppm for B20–B25–B30, and 8 ppm for B40–B50. Pure biodiesel (B100) maintains its sulfur content at 8 ppm. This declining trend suggests that biodiesel has very little sulphur by nature and that mixing it with fossil diesel lowers the fuel’s total sulphur level.

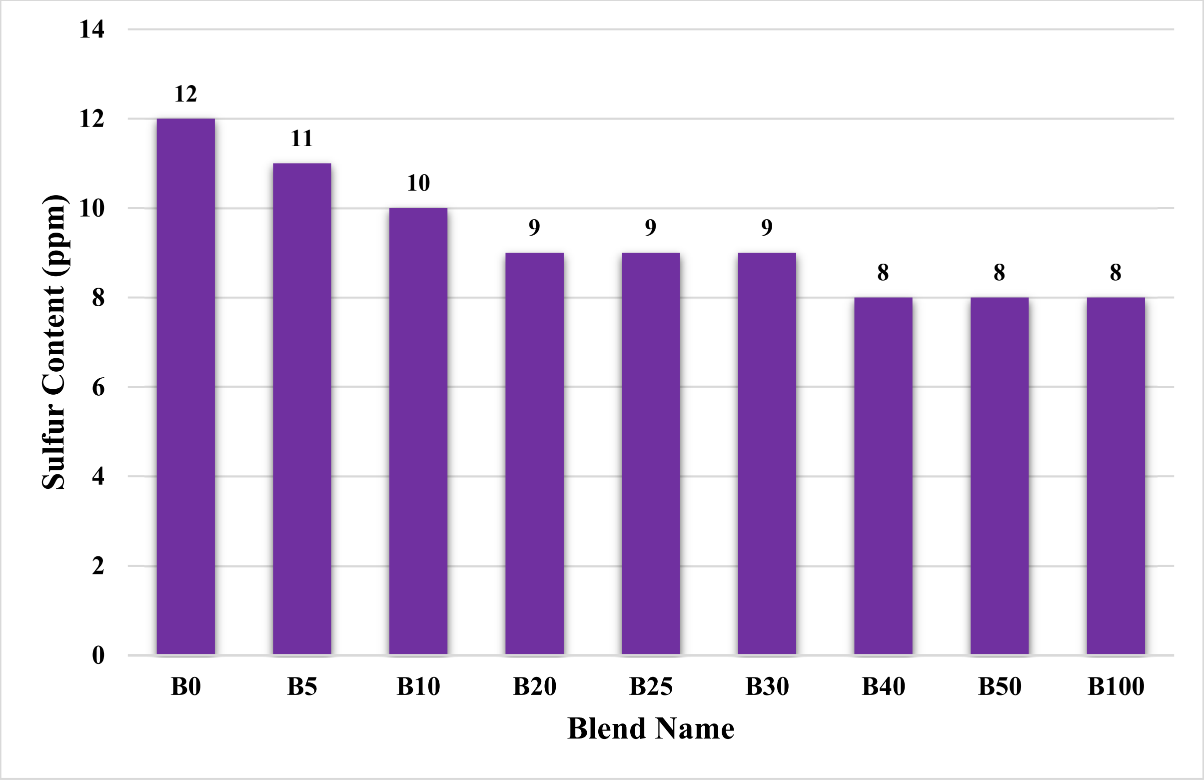


Figure 12. Variations in the sulfur content of various biodiesel-diesel blends.

From an environmental and regulatory standpoint, the sulfur content reduction is noteworthy. Acid rain and particulate matter in the atmosphere are mostly caused by sulfur oxides (SO_x) emissions, which are directly caused by sulfur in diesel fuels. Reducing the amount of sulfur in the fuel enhances air quality and makes it possible to comply with strict emission standards like ASTM D975 for ultra-low sulfur diesel or Euro VI. Cleaner combustion and less sulfate particulate matter generation in exhaust fumes are two benefits of even modest sulfur reductions, as seen in low to medium biodiesel blends (B5–B20).

Reduced sulfur content also improves the robustness and effectiveness of after-treatment systems, including selective catalytic reduction (SCR) units and diesel particulate filters (DPFs), from an engine standpoint. High sulfur fuels can poison catalysts and shorten the lifespan of emission control components. Blends of biodiesel, on the other hand, safeguard these systems, increasing their operational effectiveness and lowering the need for maintenance. One of the key sustainability benefits of biodiesel is its capacity to reduce pollutant emissions; even moderate blends (B20–B30) illustrate a discernible decrease in sulfur, while B100 has the smallest sulfur levels.

The effect of total glycerol on several biodiesel-diesel mixtures is presented in Figure 13. The overall glycerol level steadily rises with the addition of biodiesel, representing any leftover amounts from the transesterification process. For example, B5 displays 0.01 weight percent, B10 at 0.02 weight percent, B20 at 0.05 weight percent, and B25 at 0.06 weight percent. Higher blends, like B30–B50, range from 0.09 to 0.12 weight percent, with pure biodiesel (B100) reaching 0.20 weight percent.

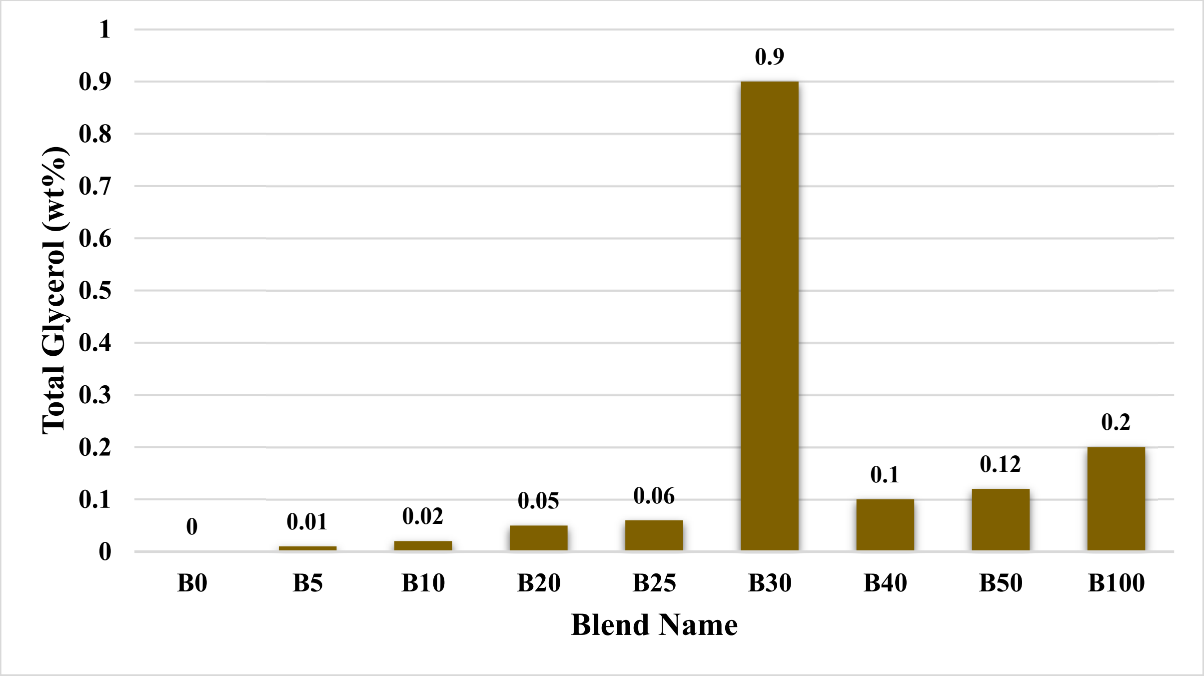


Figure 13. Impact of total glycerol on several biodiesel-diesel mixtures.

4. Conclusions

The physicochemical and combustion-related characteristics of biodiesel and its blends with petroleum diesel, such as cetane number, acid value, density, calorific value, flash point, and viscosity, were measured. The experimental results reported that gradually raising the blends' percentage of biodiesel alters the fuel's characteristics in anticipated and beneficial methods. Additionally, the flash point increased dramatically, improving handling and storage safety. With the addition of biodiesel, the cetane number increased somewhat, suggesting enhanced ignition quality and the possibility of more seamless engine performance. The finding indicated that the heating value gradually drops as biodiesel is mixed with diesel: 44.01 MJ/kg for B5, 43.59 MJ/kg for B10, 42.81 MJ/kg for B20, 42.53 MJ/kg for B25, 42.61 MJ/kg for B30, 41.81 MJ/kg for B40, 41.52 MJ/kg for B50, and 39.49 MJ/kg for pure biodiesel (B100). Besides, the cetane number slightly rises as biodiesel is incorporated into the mixture; it is 49 for B5, 50 for B10, 52 for B20–B25, 53 for B30–B40, and 54 for B100. Additionally, the flash point gradually rises as the percentage of biodiesel increases: 70 °C (B5), 80 °C (B10), 100 °C (B20), 105 °C (B25), 115 °C (B30), 120 °C (B40), 130 °C (B50), and a significantly higher value of 185 °C for pure biodiesel (B100).

Finally, it was discovered that low to medium blends (B5–B20) were completely compatible with traditional diesel engines without the need for modification, offering greater ignition and environmental performance while preserving fuel handling qualities. Although higher blends (B40–B100) provide better safety and emissions benefits, their increased viscosity and lower heating value may necessitate small changes to fuel injection systems or engine calibration. The study demonstrates that blending biodiesel is a viable and sustainable strategy to lessen dependency on fossil fuels without sacrificing diesel performance.

Author Contributions

T.M.M.A.: methodology, conceptualization, writing—original draft preparation, writing—reviewing and editing, investigation; K.A.: conceptualization, methodology, writing—original draft preparation, visualization; L.A.-M.: conceptualization, data curation, writing—original draft preparation, investigation. All authors have read and agreed to the published version of the manuscript.

Funding

This research received no external funding.

Data Availability Statement

The data presented in this study are available on request from the corresponding author.

Conflicts of Interest

The authors declare no conflict of interest.

Use of AI and AI-Assisted Technologies

No AI tools were utilized for this paper.

References

1. Mulk, W.U.; Ismael, M.A.; Aziz, A.R.A.; et al. Recent Progress in Biodiesel-Fueled ICEs and Role of Nano-Additives in Optimizing Combustion and Emissions with Cost Analysis- A Comprehensive Review. *Renew. Sustain. Energy Rev.* **2026**, *226*, 116263. https://doi.org/10.1016/j.rser.2025.116263.
2. IEA. *World Energy Outlook*; International Energy Agency: Paris, France, 2009.
3. Mulk, W.U.; Abd Aziz, A.R.; Ismael, M.A.; et al. Diesel and Oxyhydrogen Dual-Fuel: Reducing Emissions of a Diesel Engine Using Diesel-Oxyhydrogen Dual Fuel Combustion. *J. Adv. Res. Exp. Fluid Mech. Heat Transf.* **2025**, *18*, 69–80. https://doi.org/10.37934/arefmht.18.1.6980.
4. Razzak, S.A.; Zakir Hossain, S.M.; Ahmed, U.; et al. Cleaner Biodiesel Production from Waste Oils (Cooking/Vegetable/Frying): Advances in Catalytic Strategies. *Fuel* **2025**, *393*, 134901. https://doi.org/10.1016/j.fuel.2025.134901.
5. Kumar, D.; Singh, B.; Bauddh, K.; et al. Bio-Oil and Biodiesel as Biofuels Derived from Microalgal Oil and Their Characterization by Using Instrumental Techniques. In *Algae and Environmental Sustainability*; Singh, B., Bauddh, K., Bux, F., Eds.; Springer India: New Delhi, India, 2015; pp. 87–95. https://doi.org/10.1007/978-81-322-2641-3_7.
6. Kumar, M.; Ansari, N.A.; Gautam, R. Algae Biodiesel as a Alternative Green Fuel: A Futuristic Scope. *Clean Chem. Eng.* **2025**, *11*, 100178. https://doi.org/10.1016/j.clce.2025.100178.
7. Damian, C.S.; Devarajan, Y.; Jayabal, R. A Comprehensive Review of the Resource Efficiency and Sustainability in Biofuel Production from Industrial and Agricultural Waste. *J. Mater. Cycles Waste Manag.* **2024**, *26*, 1264–1276. https://doi.org/10.1007/s10163-024-01918-6.
8. Soudagar, M.E.M.; Shelare, S.; Marghade, D.; et al. Optimizing IC Engine Efficiency: A Comprehensive Review on Biodiesel, Nanofluid, and the Role of Artificial Intelligence and Machine Learning. *Energy Convers. Manag.* **2024**, *307*, 118337. https://doi.org/10.1016/j.enconman.2024.118337.
9. Yilmaz, N.; Atmanli, A. Experimental Assessment of a Diesel Engine Fueled with Diesel-Biodiesel-1-Pentanol Blends. *Fuel* **2017**, *191*, 190–197. https://doi.org/10.1016/j.fuel.2016.11.065.
10. Lima dos Santos, H.C.; Gonçalves, M.A.; da Cas Viegas, A.; et al. Tungsten Oxide Supported on Copper Ferrite: A Novel Magnetic Acid Heterogeneous Catalyst for Biodiesel Production from Low Quality Feedstock. *RSC Adv.* **2022**, *12*, 34614–34626. https://doi.org/10.1039/D2RA06923G.
11. Vellaiyan, S. Energetic Materials for Improved Performance and Ecological Metrics in Biodiesel–Diesel Blended Engines: A Comprehensive Review. *Renew. Sustain. Energy Rev.* **2026**, *226*, 116487. https://doi.org/10.1016/j.rser.2025.116487.
12. Zhang, Y.; Gao, S.; Zhang, Z.; et al. A Comprehensive Review on Combustion, Performance and Emission Aspects of Higher Alcohols and Its Additive Effect on the Diesel Engine. *Fuel* **2023**, *335*, 127011. https://doi.org/10.1016/j.fuel.2022.127011.

13. Zikri, J.M.; Sani, M.S.M.; Adam, A. Exploring the World of Diesel Engines: Analyzing Noise and Vibration Characteristics with Biodiesel Application. *Renew. Sustain. Energy Rev.* **2026**, *226*, 116168. https://doi.org/10.1016/j.rser.2025.116168.
14. Prajapati, A.K.; Mahajan, A.; Jadhav, S.M.; et al. Fourth-Generation (4G) Biodiesel: Paving the Way for a Greener and Sustainable Energy Future in Emerging Economies. *Renew. Sustain. Energy Rev.* **2026**, *225*, 116103. https://doi.org/10.1016/j.rser.2025.116103.
15. Rani, A.; Nandan, D. Alternative Fuels for Agricultural Internal Combustion Engines: Perspectives on Sustainability, Engine Compatibility, and Technology Potential. *Biomass Futur.* **2026**, *1*, 100017. https://doi.org/10.1016/j.bmf.2026.100017.
16. Meher, L.C.; Vidya Sagar, D.; Naik, S.N. Technical Aspects of Biodiesel Production by Transesterification—A Review. *Renew. Sustain. Energy Rev.* **2006**, *10*, 248–268. https://doi.org/10.1016/j.rser.2004.09.002.
17. Premkumar, D.; Jayabal, R.; Padmavathi, K.R.; et al. Ammonia-Assisted Combustion of Alcohol-Enriched Chicken Fat Biodiesel: Experimental Investigation of a Multi-Fuel Strategy in Diesel Engines. *Process Saf. Environ. Prot.* **2026**, *209*, 108577. https://doi.org/10.1016/j.psep.2026.108577.
18. Hosseinzadeh-Bandbafha, H.; Nizami, A.-S.; Kalogirou, S.A.; et al. Environmental Life Cycle Assessment of Biodiesel Production from Waste Cooking Oil: A Systematic Review. *Renew. Sustain. Energy Rev.* **2022**, *161*, 112411. https://doi.org/10.1016/j.rser.2022.112411.
19. Khan, K.H.; Mashud, M. Performance and Emission Analysis of Flaxseed Biodiesel Blends in a Direct Injection Diesel Engine. *Energy Convers. Manag. X* **2026**, *30*, 101623. https://doi.org/10.1016/j.ecmx.2026.101623.
20. Nayak, M.G. Review and Comparison of the Methodology Adopted for Biodiesel Production. *Carbon Resour. Convers.* **2026**, *9*, 100343. https://doi.org/10.1016/j.crcon.2025.100343.
21. Chamkalani, A.; Zendehboudi, S.; Rezaei, N.; et al. A Critical Review on Life Cycle Analysis of Algae Biodiesel: Current Challenges and Future Prospects. *Renew. Sustain. Energy Rev.* **2020**, *134*, 110143. https://doi.org/10.1016/j.rser.2020.110143.
22. Tibesigwa, T.; Olupot, P.W.; Kirabira, J.B. Scenario Analysis of the Long-Term Impact on Energy Demand and Emissions of B10 Use as a Clean Transport Fuel. *Front. Energy Res.* **2024**, *12*, 1403014. https://doi.org/10.3389/fenrg.2024.1403014.
23. Gautam, R.; Kumar, S. Performance and Combustion Analysis of Diesel and Tallow Biodiesel in CI Engine. *Energy Rep.* **2020**, *6*, 2785–2793. https://doi.org/10.1016/j.egyr.2020.09.039.
24. Patil, S.S.; Hulwan, D.B.; Kumbhar, V.S.; et al. Influence of Waste Cooking Oil Characteristics on the Quality of Produced Biodiesel. *Int. J. Thermofluids* **2025**, *30*, 101469. https://doi.org/10.1016/j.ijft.2025.101469.
25. Sankhyan, S.; Kumar, P.; Pandit, S.; et al. Valorization of Waste Cooking Oil: Emerging Strategies for Bio-Based Product Development. *Biomass Bioenergy* **2025**, *202*, 108244. https://doi.org/10.1016/j.biombioe.2025.108244.
26. Rinaldi, N.; Alfarez, R.H.; Sari, N.L.; et al. Activity of NiMo and CoMo Catalysts Supported on Ti-Pillared Bentonite for Converting Waste Cooking Oil into Green Diesel. *Results Chem.* **2026**, *25*, 103231. https://doi.org/10.1016/j.rechem.2026.103231.
27. Chenni, H.; Outili, N.; Kerras, H.; et al. From Waste to Value: Optimized Epoxidation of Waste Cooking Oil and Synthesis of Bio-Based Polyols. *Process Saf. Environ. Prot.* **2026**, *212*, 108843. https://doi.org/10.1016/j.psep.2026.108843.
28. Xie, Y.; Zhao, J.; Wang, H.; et al. Research Progress on Biodiesel Production Utilizing Waste Oils and Biomass-Derived Catalysts. *Fuel Process. Technol.* **2026**, *281*, 108389. https://doi.org/10.1016/j.fuproc.2025.108389.
29. Sikandar, M.; Ashiq, J.; Raza, A.; et al. Waste Cooking Oil Conversion into Multifunctional Additives to Develop Economic Bio-Lubricant. *Sustain. Chem. Pharm.* **2026**, *51*, 102353. https://doi.org/10.1016/j.scp.2026.102353.
30. Zhang, F.; Huang, B.; Cui, J.; et al. Waste Cooking Oil Biodiesel Alters Combustion Pathways to Enhance Volatile Organic Compound Emissions and Reduce Intermediate/Semi-Volatile Organic Compounds in Agricultural Machinery. *J. Hazard. Mater.* **2026**, *513*, 142450. https://doi.org/10.1016/j.jhazmat.2026.142450.
31. Alamsyah, R.; Sudarto, S.; Supriatna, N.K.; et al. Integrated Coconut Processing for Cost-Effective Sustainable Aviation Fuel and Biodiesel Production: Focus on Medium Chain Triglycerides By-Products. *Results Eng.* **2026**, *29*, 108446. https://doi.org/10.1016/j.rineng.2025.108446.
32. Chen, R.; Xue, B.; Zhu, F.; et al. The Application of Heterogeneous Catalysts in Esterification/Transesterification for Biodiesel Production. *Renew. Sustain. Energy Rev.* **2026**, *226*, 116262. https://doi.org/10.1016/j.rser.2025.116262.
33. Stojković, I.J.; Stamenković, O.S.; Povrenović, D.S.; et al. Purification Technologies for Crude Biodiesel Obtained by Alkali-Catalyzed Transesterification. *Renew. Sustain. Energy Rev.* **2014**, *32*, 1–15. https://doi.org/10.1016/j.rser.2014.01.005.