MSW MANAGEMENT -Multidisciplinary, Scientific Work and Management Journal
ISSN: 1053-7899
Vol. 36 Issue 2s, 2026, Pages 63-66

Optimization of Lemongrass Oil-Based Biodiesel Production Using Heterogeneous Catalysts: A Sustainable Approach

Sajid Husain[a], Kishan Pal Singh[b]
[a] Research Scholar, Department of Mechanical Engineering, Mangalayatan University, Aligarh 202146, Uttar Pradesh
[b] Professor, Department of Mechanical Engineering, Mangalayatan University, Aligarh 202146, Uttar Pradesh
Corresponding Author Email ID: - sajidhusain77@gmail.com

Abstract
This paper states that it is possible to optimize the production of biodiesel using lemongrass oil with a heterogeneous catalyst which provides a sustainable and environmentally friendly alternative to the existing fossil fuels. In optimized conditions, the transesterification process with the use of changes in methanol-to-oil ratio, catalyst concentration, and reaction time had a maximum yield of 93% of biodiesel. The biodiesel produced fulfilled the ASTM fuel standards with desirable density, viscosity, and flash point levels. Analysis of emissions substantiated that the emission of carbon monoxide, hydrocarbons, and smoke opacity were considerably lower than those of fossil diesel, which highlights its environmental advantage. Moreover, the heterogeneous catalyst was found to be recyclable in numerous cycles with minimum loss of efficiency which increased the economic feasibility of the process. In general, the results confirm the potential of lemongrass oil as a potential non-edible feedstock and heterogeneous catalysis as a resourceful technique in clean biodiesel production that can be effectively used in large-scale renewable energy systems.

Keywords: Biodiesel, Lemongrass Oil, Heterogeneous Catalyst, Transesterification, Renewable Energy.

1. Introduction

The growing energy demand in the world along with the very rapid depletion of the fossil fuel reserves and the related environmental issues have heightened the search of the renewable and sustainable sources of energy (Elkelawy, 2022). Biodiesel has been identified as a potential alternative to petroleum-derived diesel among the other renewable fuels because of its biodegradability, non-toxicity, and high capacity to cut down greenhouse emissions. Historically, biodiesel has been derived out of edible oils with the use of homogeneous catalysts, which presents economic and environmental problems like problems of catalyst recovery (Gowthaman, et al., 2024), soap formation and generation of wastewater.

To address these constraints, recent developments have turned to non-edible oil feedstocks and heterogeneous catalysts to increase the sustainability and affordability of biodiesel manufacture (Vino, 2019). Lemongrass (Cymbopogon flexuosus), an aromatic plant that contains high amounts of essential oils and is extensively cultivated in tropical areas, is an unexploited and unexplored an important source of non-edible oil that could be used to produce biodiesel (Hassan, 2023). It possesses high oil content, advantageous fatty acid composition as well as high growth rate, which makes it an attractive choice as a source of renewable biofuels (Prakash, 2023).

This paper sets out to optimize the biodiesel production process of lemongrass oil with a heterogeneous catalyst, with the following important parameters of transesterification of methanol-to-oil ratio, catalyst concentration, and reaction time. The fuel properties, the emission characteristics and reusability of catalyst is also evaluated to determine the environmental and economic feasibility of the process (Mahgoub, 2023). This study will help the development of sustainable fuel technologies and assist the world in switching to clean energy sources by using both the advantages of a renewable source of feedstock and a recyclable catalyst.

2. Lemongrass Biodiesel and Catalyst Optimization

The reason why lemongrass (Cymbopogon flexuosus) is selected as the biodiesel feedstock is because it is non-edible, can grow rapidly, it contains essential oil, and it can grow on poor soils (Vellaiyan, et al., 2024).

2.1. Selection of Feedstock: It does not involve the food-versus-fuel problem that is the case with edible oil such as soybean or palm oil. The triglycerides and long-chain fatty acids present in the oil extracted out of the lemongrass are suitable to be converted into biodiese (Mehra, 2023).

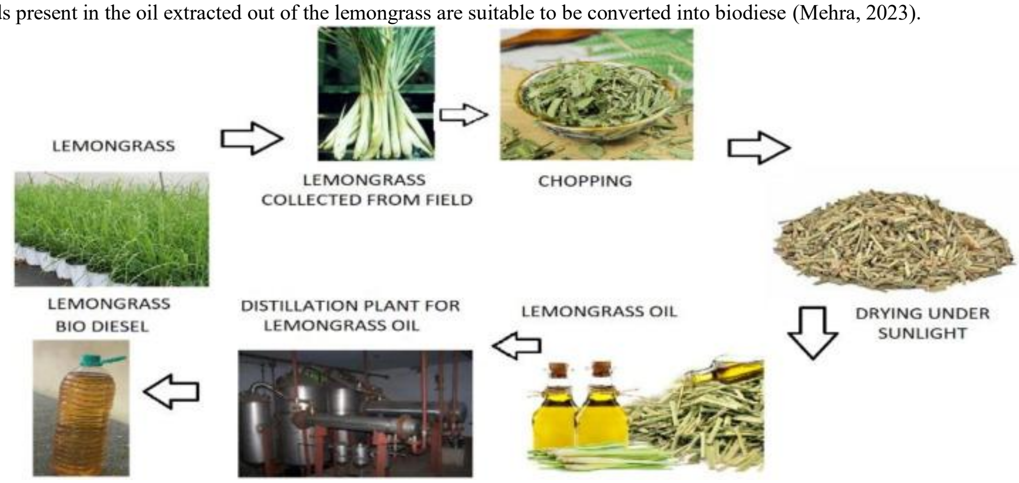

Fig.1 Lemongrass Biodiesel

2.2. Oil Extraction Process: The oil is extracted by Soxhlet extraction apparatus, a common laboratory method of extracting solvent continuously by immersing in dried lemongrass biomass. A non-polar solvent such as hexane is normally used (Sankaranarayanan, 2021). The dried plant matter is put in a thimble and the solvent is evaporated, condensed and dripped on the material repeatedly until the essential oil dissolves. The technique guarantees good recovery and purity of oil and the extract is therefore ready to be subjected to transesterification.

2.3. Transesterification Reaction: This is the most important chemical reaction that can be applied to transform lemongrass oil into biodiesel. It is the process of reacting the extracted oil (triglycerides) with an alcohol (generally methanol) in the presence of a catalyst to form fatty acid methyl esters (FAMEs) (biodiesel) and glycerol as by-product (Seeniappan,et al., 2022).

The general response is:

$$Triglyceride + Methanol \rightarrow Biodiesel\,(FAME) + Glycerol$$

To the contrary, in this work conventional homogeneous catalysts are replaced by heterogeneous catalysts. Heterogeneous catalysts are not easily separated and recycled like the heterogeneous catalysts. Examples are calcium oxide (CaO), magnesium oxide (MgO) or other solid base catalysts (Singh, 2023).

2.4. Reaction Parameters Optimization: In order to produce as much biodiesel as possible, and produce fuel of high quality, three principal reaction parameters are optimized (Thiyagarajan, et al. , 2022):

- **Methanol to oil ratio:** Unnecessary methanol causes the reaction to run to completion. Such ratios as 6:1, 8:1, and 9:1 are checked.
- **Catalyst concentration:** Changing the concentration of catalyst (e.g., 1.0%, 1.5%, 2.0%) influences on the speed and the fullness of the reaction.
- **Reaction time:** The time intervals (e.g., 60,90, 120 minutes) are also adjusted to achieve complete conversion at the minimum loss of energy.

The study yielded a high result of 93% of biodiesel under optimal conditions (9:1 methanol-oil ratio, 2% catalyst, 120 minutes) indicating that conversion was successful.

2.5. Separation and Purification: Once the transesterification reaction occurs the mixture is left to settle into two layers:

- Biodiesel (FAME) is separated diligently and is the top layer.

MSW MANAGEMENT -Multidisciplinary, Scientific Work and Management Journal
ISSN: 1053-7899
Vol. 36 Issue 2s, 2026, Pages 63-66

- The lower layer is glycerol, extra methanol and leftover catalyst.

The resulting mixture is then washed and dried to ensure there is no alcohol trace and impurities left in the mixture, resulting in the final product that can be used by the engine (Subramanian, 2022).

2.6. Fuel Property Testing: Physicochemical properties of the produced biodiesel are tested to include:

- Density
- Viscosity
- Flash point
- Calorific value

All the measured parameters are compared to the ASTM D6751 so that the quality and safety of the fuel can be used in the CI engines.

2.7. Evaluation of emission performance: Tests conducted on engines have shown that lemongrass biodiesel helps in reducing the emission of harmful gases that include:

- Carbon monoxide (CO)
- Hydrocarbons (HC)
- Smoke opacity

These environmental advantages are mainly because of the oxygen-rich nature of biodiesel that causes greater combustion than fossil diesel does.

2.8. Catalyst Reusability: One of the most significant strengths of a heterogeneous catalyst is that it can be reused in several cycles. The experiment of reusability in four cycles showed that the yield was reduced gradually (93 to 85), proving the sustainability and economic benefit of the catalyst (Subramaniyan, et al., 2025). The production of biodiesel with lemongrass oil and heterogeneous catalyst is a feasible, green, and economically viable alternative to the traditional diesel. This process has the potential of being adopted in renewable energy systems, particularly in areas where lemongrass is grown abundantly considering that it has high yield, good fuel properties, low emissions, and the catalyst can be reused.

3. Research Methodology

3.1. Research Design: The research design is experimental as the production of biodiesel in the laboratory and its performance will be tested in a controlled environment. Methanol to oil ratio, catalyst concentration and reaction time are the independent variables and biodiesel yield, fuel properties and emission characteristics are the dependent variables.

3.2. Production of Lemongrass and the Extraction of Oil: Lemongrass (Cymbopogon flexuosus) was grown on the basis of standardized agronomic practices. The oil extracted after harvesting was done in a Soxhlet apparatus, which allows continuous extraction of solvents and the highest recovery rates.

3.3. Process of Transesterification: A transesterification process was done on the extracted oil. The alcohol applied was methanol and a solid heterogeneous catalyst was added to make the reaction possible. The procedure has been carried out in different conditions to identify the best settings:

- **Methanol-to-oil ratios:** 6:1, 8:1 and 9:1
- **Catalyst concentrations:** 1.0, 1.5, and 2.0 percent
- **Reaction times:** 60, 90 and 120 minutes

3.4. Selection of the Catalyst: The choice of a heterogeneous catalyst was made on the basis of its thermal stability, large surface area, ease of separation and reusability. In contrast to homogeneous catalysts, heterogeneous catalysts enable cleaner separation of products and less environmental damage (Vijayakumar, et al. , 2016).

3.5. Evaluation Criteria: Physicochemical properties of the output biodiesel are tested according to the ASTM standards. Reusability of catalyst and emission features were also determined. Simulation and prediction of yield trends was done using machine learning tools.

4. Results and Discussion:

This section presents a detailed analysis of the experimental outcomes related to the production and performance of lemongrass oil-based biodiesel.

4.1. Fuel Property Evaluation: Analysis of the biodiesel produced was carried out by physical and chemical properties as per the ASTM standards. Density, viscosity, flash point and calorific value are noted.

Table 1. Fuel Properties of Lemongrass Oil-Based Biodiesel Compared to Diesel

Property	Diesel	Lemongrass Biodiesel
Density (kg/m3)	830	875
Viscosity (mm2/s)	2.5	4.8
Flash Point (°C)	60	148
Calorific Value (MJ/kg)	45	39.2

As can be seen in Table 1, the fuel property analysis of the lemongrass oil-based biodiesel has a big difference with the conventional diesel. The biodiesel density was measured as 875 kg/m 3 as opposed to 830 kg/m 3 of diesel. This higher density means that there is more energy content per unit volume, but it has a slight influence on fuel injection properties. Biodiesel also has higher viscosity (4.8 mm 2 /s) compared to that of diesel (2.5 mm 2 /s) and this makes it to have superior lubrication abilities but may have an effect on atomization in CI engines. The flash point of the biodiesel was significantly higher at 1480C than that of diesel at 600C and this made the biodiesel safer in regard to handling and storage since it is less flammable. The calorific value of biodiesel (39.2 MJ/kg) was however lower than that of diesel (45 MJ/kg) implying that it had a slight decrease in energy production per kilogram. Nonetheless, the characteristics of the biodiesel are within the acceptable ASTM limits, and this proves that the biodiesel is viable as an alternative to fossil diesel as it is renewable.

4.2. Biodiesel Yield Analysis

Factors that affected the yield were the concentration of catalyst, methanol to oil ratio and the reaction time. The enhanced conditions gave a good conversion rate.

Table 2.Biodiesel Yield Under Various Conditions

Methanol: Oil Ratio	Catalyst (%)	Time (min)	Yield (%)
6:1	1.0	60	78
8:1	1.5	90	88
9:1	2.0	120	93

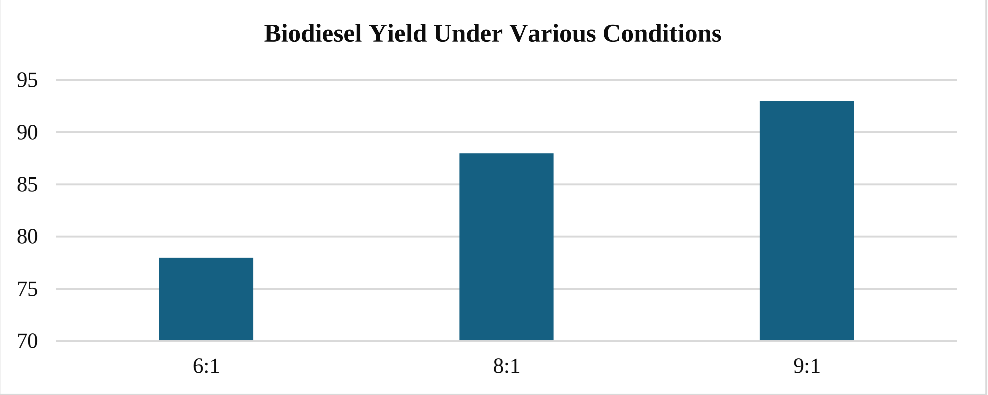

Fig.2 Biodiesel Yield Under Various Conditions

MSW MANAGEMENT -Multidisciplinary, Scientific Work and Management Journal
ISSN: 1053-7899
Vol. 36 Issue 2s, 2026, Pages 63-66

A comparison of the yield of biodiesel and the effect of different methanol-to-oil ratios, catalyst concentration and reaction time is shown in Table 2. The data show a definite tendency of the rise of the yield in the process of the optimization of these parameters. The yield was 78% at a methanol-to-oil ratio of 6:1 and 1.0 percent catalyst in 60 minutes of reaction time. When the ratio of methanol to oil was raised to 8:1 with 1.5 percent catalyst and 90 minutes reaction time, the yield rose to a very high value of 88 percent. Optimized condition of 9:1 methanol-to-oil ratio, 2.0% catalyst concentration and 120 minutes reaction time yielded the maximum of 93 percent. This gradual rise in yield shows the significance of adequate availability of methanol and catalyst loading in ensuring that transesterification reaction is taken to completion. It also puts a strong emphasis on the importance of sufficient reaction time in order to obtain maximum conversion efficiency. Such conclusions prove that increased ratios of methanol and catalyst concentrations, as well as extended reaction times, increase the overall yield of biodiesel production.

4.3.Catalyst Reusability

The heterogeneous catalyst retained significant activity over multiple cycles, making it a cost-effective option.

Table 3. Catalyst Reusability Over Cycles

Cycle Number	Yield (%)
1	93
2	90
3	88
4	85

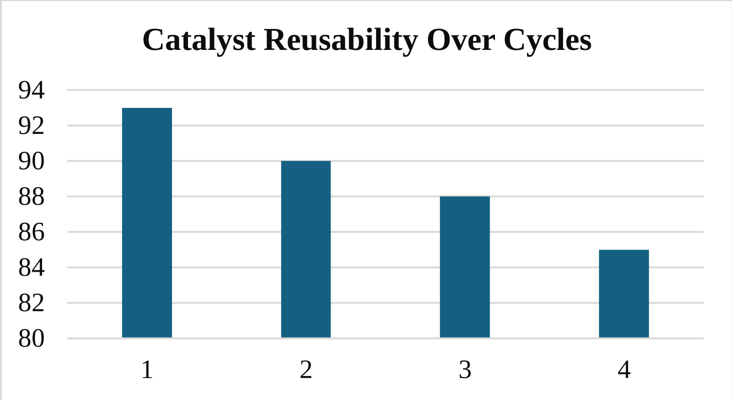

Fig.3 Catalyst Reusability Over Cycles

Table 3 shows the reusability efficiency of the heterogeneous catalyst in the four successive cycles of transesterification. The catalyst used in the first cycle produced a maximum yield of 93 percent that subsequently reduced to 90 percent, 88 percent and 85 percent in the second, third and fourth cycle, respectively. This progressive decrease in the yield is a sign of a minor loss of catalytic activity on successive reuses, probably by factors like surface fouling, loss of active sites or degradation of the structure of the catalyst. Nevertheless, the yield of the catalyst was still quite high after four cycles, which proves its high durability and cost-effectiveness. The possibility of reusing the catalyst without much loss of efficiency is part of what makes the biodiesel production process economically and environmentally sustainable since less of the fresh catalyst is required to be put into this process and the waste produced is minimal.

4.4.Environmental Benefits

The use of heterogeneous catalysts reduced soap formation, simplified product separation, and minimized wastewater generation. The lemongrass biodiesel displayed reduced CO, HC, and smoke emissions compared to fossil diesel.

Table 4. Comparative Emission Characteristics

Fuel Type	CO (g/kWh)	HC (g/kWh)	Smoke Opacity (%)
Fossil Diesel	2.4	1.2	35
Lemongrass Biodiesel	1.6	0.7	20

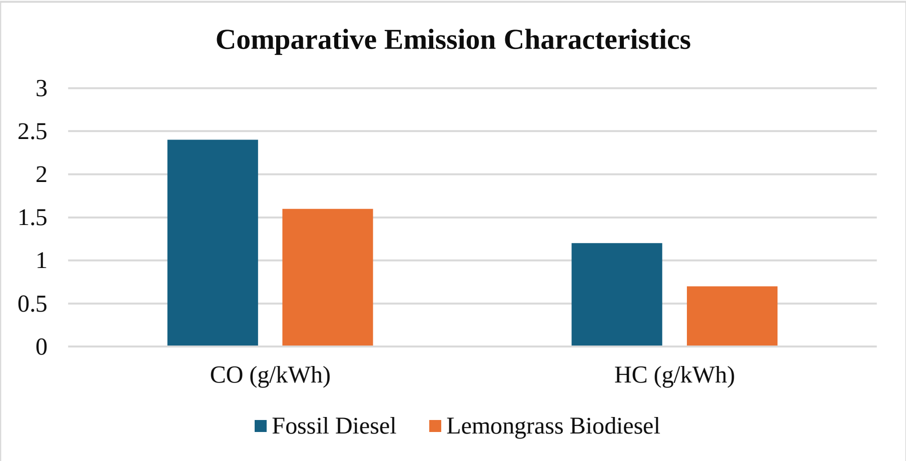

Fig.4 Comparative Emission Characteristics

The emission properties of lemongrass biodiesel and conventional fossil diesel are compared in Table 4 and it is noted that the environmental benefits of using biodiesel. There was also a notable lowering of the carbon monoxide (CO) emission in the lemongrass biodiesel which was reduced to 1.6 g/kWh as compared to diesel that emitted 2.4 g/kWh. In the same manner, the hydrocarbon (HC) emissions were cut to 0.7 g/kWh down to 1.2 g/kWh. Besides, smoke opacity which is a major indicator of particulate emissions reduced significantly by 35 percent when using diesel to 20 percent when using biodiesel. Such reductions have been explained by the increased oxygen content of biodiesel that enables better combustion. Also, biodiesel burns cleaner and there is no sulfur hence less particulate matter and formation of pollutants. All in all, these results show that lemongrass biodiesel is a more eco-friendly fuel, which can provide significant cuts in dangerous emissions, and, therefore, allows promoting cleaner air and less impact on the environment.

5. Conclusion

The study is able to prove the feasibility of biodiesel production of lemongrass (Cymbopogon flexuous) oil with heterogeneous catalyst proving the fact that it is both environmentally and economically sustainable. The paper identifies the importance of optimizing the transesterification parameters, namely the methanol-to-oil ratio, concentration of catalyst and reaction time in order to maximize the biodiesel yield. This confirmed the efficiency of the process since a high yield of 93% was attained under optimized conditions (9:1 methanol-to-oil ratio, 2% catalyst, 120 minutes). The biodiesel produced also met the major physicochemical characteristics as required by ASTM D6751, thus it could be used in compression ignition engines without any major modification. In addition, the biodiesel produced performed better in emissions than the conventional diesel and it significantly reduced carbon monoxide, hydrocarbons and smoke opacity. Such gains can be explained through the oxygenated composition of biodiesel and the more clean-burning process it facilitates. The fact that the heterogeneous catalyst could be reused up to four times with a relatively low loss of activity was another remarkable benefit of the process, which highlights the cost-efficiency and feasibility of this method in the long-term application. The use of a non-edible, fast-growing, and locally available feedstock, in turn, dispels the food-versus-fuel controversy and encourages agricultural diversification. The results make lemongrass oil based biodiesel a very attractive alternative source of energy that can play a significant role in enhancing energy security in the world, rural development, and saving the planet. Potential future studies could entail scale-up, life cycle assessment, or integration with waste biomass valorization to create an overall and circular biofuel production system.

References

1. Elkelawy, M., El Shenawy, E.A., Bastawissi, H.A.E., Shams, M.M., Panchal, H., 2022. A comprehensive review on the effects of diesel/biofuel blends with nanofluid additives on compression ignition engine by response surface methodology. *Energy Conversion and Management: X*. 14, 100177.
2. Gowthaman, S., Anu KarthiSwaghatha, A.I., Thangavel, K., Muthulakshmi, L., Paramasivam, P., 2024. Effect of ZnO nanoparticle on combustion and emission characteristics of a diesel engine powered by lemongrass biodiesel: an experimental approach. *Discover Applied Sciences*. 6(7), 344.
3. Hassan, T., Rahman, M.M., Rabbi, M.S., Rahman, M.A., Meraz, R.M., 2023. Recent advancement in the application of metal based nanoadditive in diesel/biodiesel fueled compression ignition engine: a comprehensive review on nanofluid preparation and stability, fuel property, combustion, performance, and emission characteristics. *Environmental Progress & Sustainable Energy*. 42(2), e13976.
4. Mahgoub, B.K., 2023. Effect of nano-biodiesel blends on CI engine performance, emissions and combustion characteristics–Review. *Heliyon*. 9(11).
5. Mehra, D., Kumar, V., Choudhary, A.K., Awasthi, M., 2023. Performance and emission characteristics of CI engine using hydrogen enrichment in biodiesel blend with additives—a review. *Journal of Renewable and Sustainable Energy*. 15(3).
6. Prakash, P., Dhanasekaran, C., 2023. Influencing parameter optimisation of CRDI engine fuelled with lemongrass biodiesel blends. *International Journal of Ambient Energy*. 44(1), 719–738.
7. Sankaranarayanan, G., Venkatraman, M., Munuswamy, D.B., Ravisankar, R., 2021. Environment-friendly fuel *Cymbopogon flexuosus*: analysis of fuel properties, performance, and emission parameters of a direct injection compression ignition research engine. *Heat Transfer*. 50(7), 6589–6627.
8. Seeniappan, K., Venkatesan, B., Krishnan, N.N., Kandhasamy, T., Arunachalam, S., Seeta, R.K., Depoures, M.V., 2022. A comparative assessment of performance and emission characteristics of a DI diesel engine fuelled with ternary blends of two higher alcohols with lemongrass oil biodiesel and diesel fuel. *Energy & Environment*. 33(6), 1134–1159.
9. Singh, B., Srivastava, A.K., Prakash, O., 2023. A comprehensive review on rare biodiesel feedstock availability, fatty acid composition, physical properties, production, engine performance and emission.
10. Subramanian, L.S., Ganesan, S., Venkatesan, S.P., Muniappan, P., Pugazhenthi, R., 2022. Experimental analysis of VCR diesel engine exhaust emissions with zirconium dioxide and basalt based catalytic converter using lemon grass oil. *Materials Today: Proceedings*. 60, 1949–1958.
11. Subramaniyan, M., Manickam, S., Gurusamy, M., 2025. Experimental investigation of benzyl alcohol premixing effect on 5E concepts of compression ignition engine powered with lemongrass oil–diesel blend using response surface methodology. *Biofuels*. 1–18.
12. Thiyagarajan, S., Varuvel, E., Karthickeyan, V., Sonthalia, A., Kumar, G., Saravanan, C.G., Pugazhendhi, A., 2022. Effect of hydrogen on compression-ignition (CI) engine fueled with vegetable oil/biodiesel from various feedstocks: a review. *International Journal of Hydrogen Energy*. 47(88), 37648–37667.
13. Vellaiyan, S., Kandasamy, M., Chandran, D., Raviadaran, R., Ramalingam, K., Devarajan, Y., 2024. Characterization and optimization of waste-derived biodiesel utilizing CNT/MgO nanocomposite and water emulsion for enhanced performance and emission metrics. *Case Studies in Thermal Engineering*. 55, 104173.
14. Vijayakumar, C., Ramesh, M., Murugesan, A., Panneerselvam, N., Subramaniam, D., Bharathiraja, M., Sathiyamoorthi, R., 2016. Biodiesel from plant seed oils as an alternate fuel for compression ignition engines—a review. *Environmental Science and Pollution Research*. 23, 24711–24730.
15. Vino, V.J.A., George, J., 2019. Performance Analysis of Diesel Engine Fueled with Lemon Grass Oil/Diesel Fuel Blends. *International Journal of Psychosocial Rehabilitation*. 23(3), 279–291.