International Journal of Computer Information Systems and Industrial Management Applications
ISSN 2150-7988 Volume 18(14s) 2026 pp. 804-812
https://doi.org/10.70917/ijcisim-2026-4284
Article

Performance and Emission Characteristics of CI Engine Fueled with Lemongrass Biodiesel-Diesel Blends and Prediction Using Ml Techniques

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Abstract: The increased fears regarding depletion of fossil fuels and pollution of the environment have amplified the hunt toward sustainable and renewable sources of energy like biodiesel. A non-edible biomass source, and underutilized resource, lemongrass (Cymbopogon flexuosus) oil, has been considered as a potential feedstock source of biodiesel because of its high oil content, and because of its good combustion characteristics. In this paper, the authors will attempt to measure the performance and emission features of a single-cylinder compression ignition (CI) engine operated on different blends (B10 to B100) of lemongrass biodiesel and fossil diesel. The biodiesel was synthesized under optimal conditions of transesterification process with heterogeneous catalyst and its blends were tested across different engine loading conditions. The important engine performance parameters such as Brake Thermal Efficiency (BTE), Specific Energy Consumption (SEC), and Hydrocarbon (HC) emissions were recorded. Also, an Artificial Neural Network (ANN) based machine learning model was designed to provide an estimate of biodiesel yield as a function of catalyst concentration. The outcomes indicated that B10 had the best BTE (33.81%) at full load, whereas B20 had the least SEC (10.3 MJ/kWh), which means that the combustion was efficient. B50 had the lowest HC values (32 ppm) confirming the ecological superiority of mid-range blends. ANN model demonstrated very good predictive accuracy with deviation between +0.5 and -0.5 percent of observed real yield values. To sum up, blends of lemongrass biodiesel with diesel, especially in lower and mid blends, are good candidates to be used in CI engines with improved performance and minimal emission, and ML tools present an excellent predictive tool that can be used to optimize biodiesel production.
Keywords: Lemongrass Biodiesel, CI Engine, Brake Thermal Efficiency, Specific Energy Consumption, Hydrocarbon Emissions, Artificial Neural Network, Renewable Energy, Heterogeneous Catalyst.

1. Introduction

The constantly growing demand of energy in the world, as well as the growing fear of depletion of fossil fuel, greenhouse gases emissions and environmental contamination has forced researchers and industries to look at alternative and sustainable sources of energy. Biodiesel is one of the many renewable fuels that have been found to be a potential alternative to the use of conventional diesel fuel because of its biodegradability, low level of sulfur and capacity to decrease the net carbon emissions. Biodiesel has a broad feedstock base of edible oils, non-edible oils, waste cooking oils and animal fats. The application of edible oils however triggers food security issues, and there is need to investigate the non-edible and locally available plant-based resources.

Lemongrass (Cymbopogon flexuous) is a non-edible, aromatic, fast growing plant that is adapted to the tropical and subtropical climate. It is extensively grown as a source of essential oil and due to high oil content and good fatty acid profile, it is a promising source of biodiesel. In addition, the production of biofuel using lemongrass oil contributes to the use of underutilized biomass sources and the economy of rural farmlands. Lemongrass oil when subjected to transesterification by a heterogeneous catalyst produces biodiesel that can be used with compression ignition (CI) engines.

Assessment of biodiesel performance in current engines is one of the major steps in the research on biodiesel. This will involve checking the important performance indicators like Brake Thermal Efficiency (BTE) and Specific Energy Consumption (SEC) and the environmental factors like hydrocarbon (HC) and carbon monoxide (CO) emissions. To achieve this, it is necessary to establish how various biodiesel-diesel blends respond to different engine loads to establish the best blending ratios that can allow an engine to perform well and at the same time emit minimum emissions.

Simultaneously with experimental approaches, machine learning (ML) has been used as an effective mechanism of modeling and predicting engine behavior depending on biodiesel properties and operational parameters. Artificial Neural Networks (ANN) and Adaptive Boosting (AdaBoost) are some of the techniques that researchers can use to establish predictive models capable of estimating engine output measures with high precision. This method does not only complement experimental testing but has scalability, quicker analysis, and optimizations abilities of future engine-fuel system designs.

The purpose of this research paper is to fully assess the performance and emission attributes of a single-cylinder CI engine powered on different lemongrass biodiesel-diesel blends (B10 to B100). Moreover, ANN and AdaBoost models are combined in the study to forecast the main parameters of the engine, and the hybrid system offers a powerful solution, which is a combination of a real-life experiment and intelligent computational modeling. The results of the present research add to the existing body of knowledge that states in favor of non-edible biodiesel usage and AI implementation into the renewable energy system.

2. Theoretical Framework

2.1. Biodiesel as an Alternative Fuel

Biodiesel is a biodegradable, non-toxic, and renewable alternative fuel mostly made of biological materials like vegetable oil, animal fat, and other biomass with high lipid content. It is manufactured by means of a chemical reaction known as transesterification where triglycerides are mixed with an alcohol (usually methanol) in the presence of a catalyst to create fatty acid methyl esters (FAME) as well as glycerol. Among the major benefits of biodiesel is that it can be used in the current diesel engines without necessitating any significant changes. Also, biodiesel is safer and environmentally friendly since it has less or no sulfur, greater lubricity, and a greater flash point than fossil diesel.

Biodiesel also has a considerable potential to minimize the disastrous tailpipe emissions, including unburned hydrocarbons (HC), carbon monoxide (CO), and particulate matter (PM), compared to fossil diesel. In addition, since biodiesel can be produced through renewable materials, it will not add as much to net greenhouse gas accumulation by looking at the complete life cycle. Although it has many benefits, higher viscosity, low-energy density, and stability to oxidation require to be overcome depending on the feedstock and production process.

2.2. Lemongrass Oil-Based Biodiesel

Lemongrass (Cymbopogon flexuous) is a perennial grass, commonly grown due to its essential oil, mostly in the tropical and subtropical parts of the world. Lemongrass oil is not edible and has large amounts of long-chain fatty acids and oxygenated products, so it can be used to produce biodiesel. The physicochemical properties of the biodiesel obtained by the transesterification of lemongrass oil in the presence of heterogeneous catalyst, e.g., calcium oxide (CaO), are also desirable: density, viscosity, and a rather high cetane number are acceptable.

There is also an intrinsic advantage of lemongrass biodiesel since its molecular structure is rich in oxygen, which enhances a more complete combustion resulting to reduced emissions of CO and HC. Moreover, as a non-edible feedstock, its utilization in biodiesel production does not disrupt food security making it free of a criticism leveled against edible oil-based biodiesel. Lemongrass has a very wide availability, short growth cycle and adaptability, which further improves its viability as a sustainable biodiesel feedstock.

2.3. CI Engine Performance Indicators

Compression Ignition (CI) engines are widely applied in heavy-duty transport, agricultural and power generation industries because of the high thermal efficiency and reliability. In assessing the appropriateness of the alternative fuel such as biodiesel in CI engines, a number of performance and emission parameters are employed:

- **Brake Thermal Efficiency (BTE):** This is the capacity of the engine to transform the chemical energy of the fuel to mechanical energy. The greater the BTE, the more efficiencies in combustion and the lesser the fuel consumed.

- **Specific Energy Consumption (SEC):** The amount of energy (usually in MJ/kWh) that is required to produce a unit of power. The lower the SEC values the better the engine performance.
- **Emission Metrics:** The emission of most important pollutants such as carbon monoxide (CO), unburned hydrocarbons (HC), nitrogen oxides (NOx), and smoke opacity is monitored. These emissions are directly related to the composition of the fuel, quality of combustion and fuel oxygen content. Biodiesel has a natural oxygen content that tends to decrease CO and HC and possibly increase NOx levels based upon blend ratio and engine characteristics.

2.4. Role of Machine Learning in Engine Modeling

The use of Machine Learning (ML) in predicting engine performance and emissions has been on the rise because it can be used to model highly non-linear and complex systems without any physical equations being specified. ML models come in handy especially when the classical modeling approaches are not sufficient in cases where there is a variation in fuel properties, combustion dynamics, and operating conditions in the real world.

- **Artificial Neural Networks (ANN):** ANN is based on a neural structure in the human brain and can learn a complex relationship between input (e.g. blend ratio, engine load) and output variables (e.g. BTE, SEC, HC). It is very efficient in modelling non-linear and multidimensional ties and can be fitted to diverse amounts of data.
- **Adaptive Boosting (AdaBoost):** AdaBoost is an ensemble learning algorithm, which enhances the predictive accuracy of multiple, weak learners (usually decision trees) by training them together into a single powerful model. It is particularly useful when accuracy and strength is demanded.

ANN and AdaBoost may be trained on experimental engine test data to predict important performance measures. The predictions assist in optimum fuel blend and engine adjustments without the time consuming and expensive experimental runs, thus saving on time, cost and resources. Real-time diagnostics and control Real-time diagnostics and control Intelligent engine management systems can also be implemented using ML models, providing a route to more intelligent, efficient combustion technologies.

3. Research Methodology

3.1. Research Design

The research design is experimental research design that encompasses synthesis of biodiesel in the laboratory and testing of engine performance. It aims at quantifying and comparing the performance of combustion and emissions of different blends of biodiesel and diesel, and then model them predictively via the use of machine learning. The experiments were designed in such a way that they can be replicated and that they are reproducible and empirical observations can be validated.

3.2. Biodiesel Preparation

The extraction of lemongrass oil was done in a Soxhlet apparatus using hexane. Optimized conditions of transesterification were then applied on the oil with a heterogeneous catalyst and methanol. The mixture was then left to settle and the upper layer of biodiesel was removed, washed in warm water to wash off the impurities and dried. The last biodiesel was mixed in volumes with commercial diesel to get B10, B20, B30, B50 and B100 mixtures.

3.3. Experimental Setup

A single cylinder, four stroke, water-cooled, direct injection diesel engine was used coupled with eddy current dynamometer to conduct performance tests. The engine was run at constant speed and load varied.

Instruments and Measurement Devices:

- **Fuel consumption:** Measured with the help of a burette and a stopwatch.
- **Emission parameters (HC, CO):** Determined with the help of AVL DiGas 444 five-gas analyzer.
- **Smoke opacity:** Measurement is carried out by AVL 437C smoke meter.
- **Engine load:** This is regulated by eddy current dynamometer.

The tests were performed under five types of load conditions of 0%, 25%, 50%, 75% and 100%. All the blends were tested under the same conditions to be consistent.

3.4. Model Development of Machine Learning

ML models were trained with experimental data acquired in the course of testing an engine (input parameters: blend ratio, engine load; output parameters: BTE, SEC, HC).

Artificial Neural Network (ANN): Back propagation network of multilayered feedforward was applied. The data was divided into training (70%), test (15%) and validation (15%) sets.

- Adaptive Boosting (AdaBoost): It is applied with decision tree regressors as base-learners and trained on the same experimental dataset.
- The models were tested by:
- R 2 (coefficient of determination)
- MAE (mean absolute error)
- RMSE (root mean square error)

3.5. Evaluation and Validation

The performance of each of the blends was benchmarked with baseline diesel (B0) at all loads. The actual test data was compared with predicted values of ANN and AdaBoost to determine accuracy. The model performance was visualized by graphs and error analyses. The models assisted to generalize trends and forecast the behavior of the engine in the untested conditions and made the experimental results more useful.

4. Results and Discussion

In this section, the results of the performance and emission test of CI engine with lemongrass biodiesel-diesel blends at different loads are given. Important parameters like BTE, SEC, and HC emissions are examined to determine the effectiveness of blends. Also, the ANN-based forecasts of biodiesel yield are analyzed to confirm the correctness of machine learning in the model of engine performance.

4.1. Brake Thermal Efficiency (BTE)

Brake Thermal Efficiency is one of the most important performance indicators that shows the efficiency of the engine in converting the chemical energy of the fuel into mechanical work. The table below shows BTE values of different mixtures between lemongrass biodiesel and diesel (B0 to B100) at different engine load conditions.

Table 1. Brake Thermal Efficiency (BTE) at Different Loads for Various Blends

Load (%)	B0	B10	B20	B30	B50	B100
0	25.75	24.65	24.30	24.16	27.20	25.17
25	26.79	29.37	26.30	25.48	26.66	25.27
50	29.97	30.15	29.36	29.47	29.10	29.56
75	33.28	30.30	28.13	29.64	28.86	30.10
100	32.65	33.81	30.41	30.88	32.18	32.56

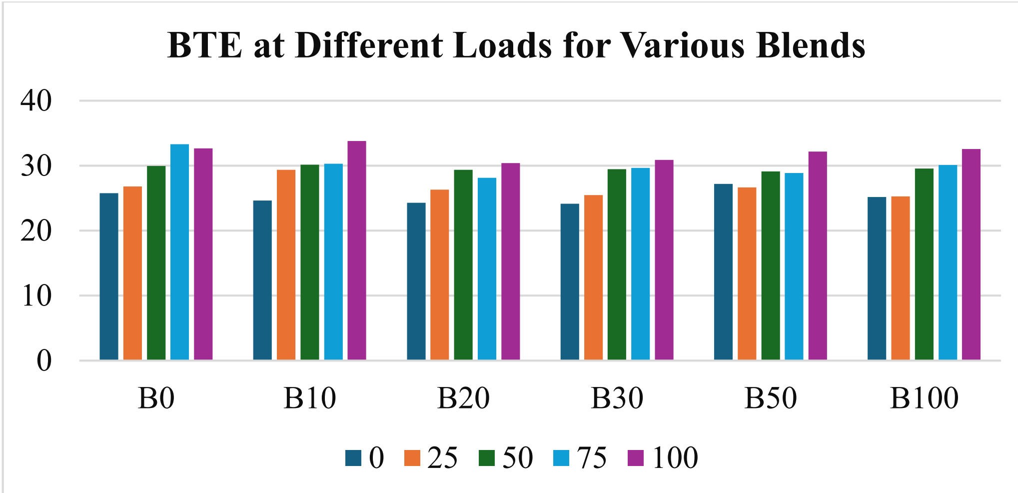

Fig. 1. Brake Thermal Efficiency (BTE) at Different Loads for Various Blends

The values of Brake Thermal Efficiency (BTE) presented in Table 1 indicate the effect of blending and the loading of biodiesel on the combustion efficiency of a CI engine. BTE values were relatively low at zero load across all blends, as would be expected with less than ideal combustion at low engine stress. With the increment in load, there was a steady rise in BTE with all fuel types and the highest BTE values were reported at full load. B10 had the highest BTE of 33.81 percent at full load even beating the conventional diesel (B0), which had 32.65 percent. This is due to the fact that biodiesel is oxygenated and therefore it burns more completely resulting in increased efficiency. B20 also competed well, particularly in the mid to high loads, which points out to it as a viable mix in the everyday functioning of the engine. Though the higher blends had a lower BTE at intermediate loads, they were good full-load performers (B50 and B100). These trends justify the conclusion that lemongrass biodiesel especially in low blend ratios can be profitably applied in CI engines with little or no reduction in performance.

4.2. Specific Energy Consumption (SEC)

Specific Energy Consumption (SEC) is an important performance measure which shows the energy consumed to produce a certain useful work by the engine and is normally measured in megajoules per kilowatt-hour (MJ/kWh). It gives a definite indication of the fuel energy efficiency when the engine is running. When the SEC values are lower, the fuel economy is higher and the overall combustion efficiency is good. The table below is the SEC values of various lemongrass biodiesel-diesel blends at varying engine loads.

Table 2. Specific Energy Consumption (SEC) at Different Loads for Various Blends

Load (%)	B0	B10	B20	B30	B50	B100
0	14.2	13.8	13.7	13.5	13.4	13.6
25	13.1	12.8	12.7	12.5	12.4	12.6
50	12.2	12.0	11.8	11.7	11.6	11.7
75	11.4	11.2	11.0	10.9	10.7	10.8
100	10.7	10.5	10.3	10.2	10.0	10.1

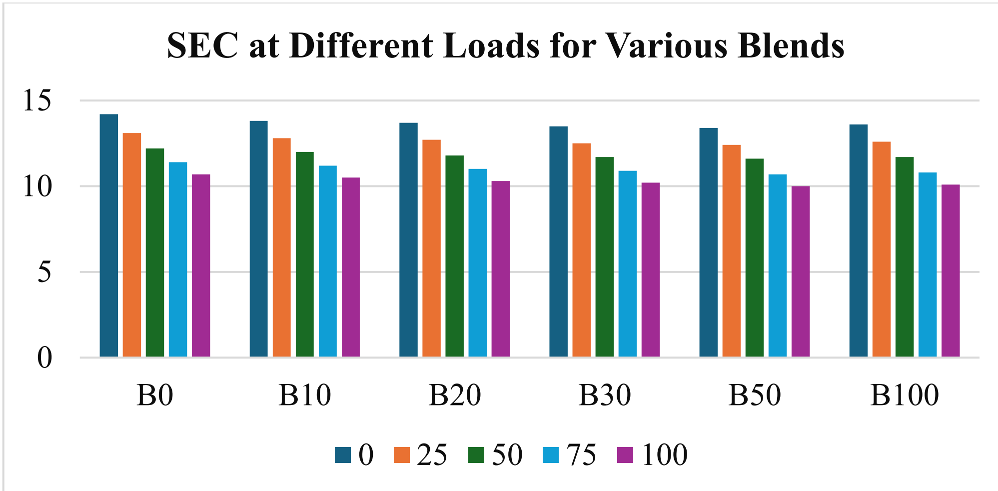

Fig.2 Specific Energy Consumption (SEC) at Different Loads for Various Blends

The SEC values in Table 2 show a steady decline with rise in engine load across all fuel blends which is common as the combustion becomes more efficient and more energy is extracted with higher engine loads. All the blends were found to have better fuel economy at full load with the lowest SEC of 10.3 MJ/kWh recorded by B20, against 10.7 MJ/kWh recorded by conventional diesel (B0). It implies that B20 is the optimal combination of combustion quality and energy content. The lower SEC values of B30, B50 and B100 full load also indicates the positive effect of the oxygen content of biodiesel although a slight improvement in performance was still registered in B20. On the whole, the data confirm that the addition of lemongrass biodiesel to diesel, especially in lower proportions, can increase energy efficiency without affecting the engine performance.

4.3. Hydrocarbon (HC) Emissions

A major indicator of incomplete combustion in internal combustion engines is Hydrocarbon (HC) emissions. These emissions are as a result of unburned fuel being released through the exhaust and these cause atmospheric pollution and the formation of smog. The determination of the HC levels assists in the evaluation of the efficiency of the fuel mixture combustion in the engine cylinder. Owing to its innate oxygen content, biodiesel tends to favor complete combustion, which reduces HC emission. The following table shows the levels of HC emissions (in parts per million, ppm) of various lemongrass biodiesel-diesel blends at various loads on the engine.

Table 3. Hydrocarbon (HC) Emissions at Different Loads for Various Blends

Load (%)	B0	B10	B20	B30	B50	B100
0	48	53	45	44	42	49
25	52	50	40	38	36	42
50	50	48	39	36	34	40
75	47	45	37	35	33	38
100	46	44	36	34	32	39

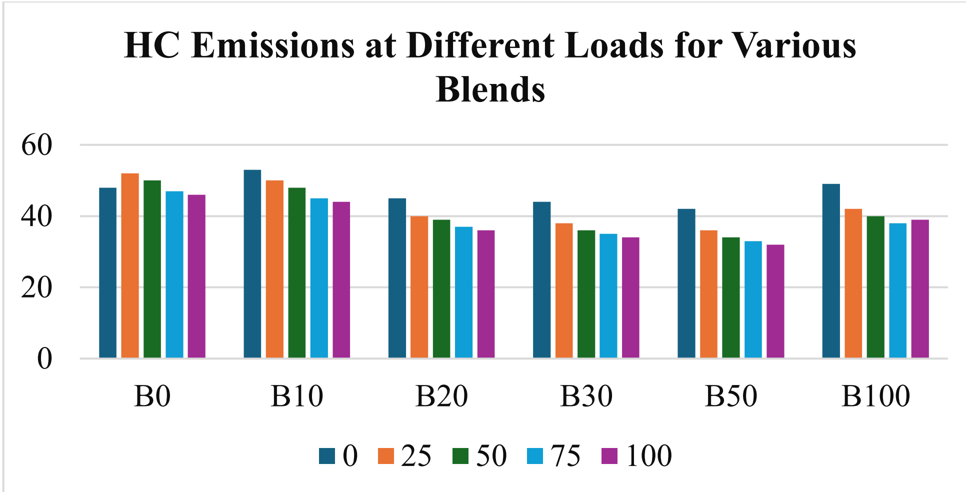

Fig.3 Hydrocarbon (HC) Emissions at Different Loads for Various Blends

Table 3 results indicate a general reduction of HC emissions with engine load across all fuel blends, which means better combustion at higher loads. B50 was the lowest emitter of HC at full load which was 32 ppm followed by B30 and B20. This is due to the fact that biodiesel has more oxygen content which enhances complete burning and hence leads to less production of unburned hydrocarbons. Interestingly, the lower blends such as B10 had higher HC emissions at idle (0% load) but there was a consistent decrease in emissions as the load increased. B100 also showed a significant improvement as compared to diesel at high loads but not as much as B50. These results imply that the mid-level blends (especially B30 and B50) strike a balance between the fuel quality and combustion efficiency resulting in the minimum HC emissions and environmental effects.

4.4. Machine Learning Prediction (ANN Model)

Artificial Neural Networks (ANN) is strong machine learning methods that can model complicated nonlinear relationships between input and output variables. In the present research, an ANN model was created to forecast biodiesel output as per concentration of the catalyst in transesterification. Experimental data were used to train the model, which allows it to acquire patterns underlying the data and generalize effectively to new inputs. In the table below, the actual biodiesel yields are compared to the ones forecasted with the ANN model to assess the applicability of the model and its accuracy to real-time biodiesel yield forecasting in biodiesel production.

Table 4. ANN Prediction of Biodiesel Yield at Various Catalyst Concentrations

Catalyst (%)	Actual Yield (%)	Predicted Yield (ANN)
1	81.2	80.8
2	87.4	86.9
3	91.8	92.1
4	89.6	89.2
5	85.0	84.7

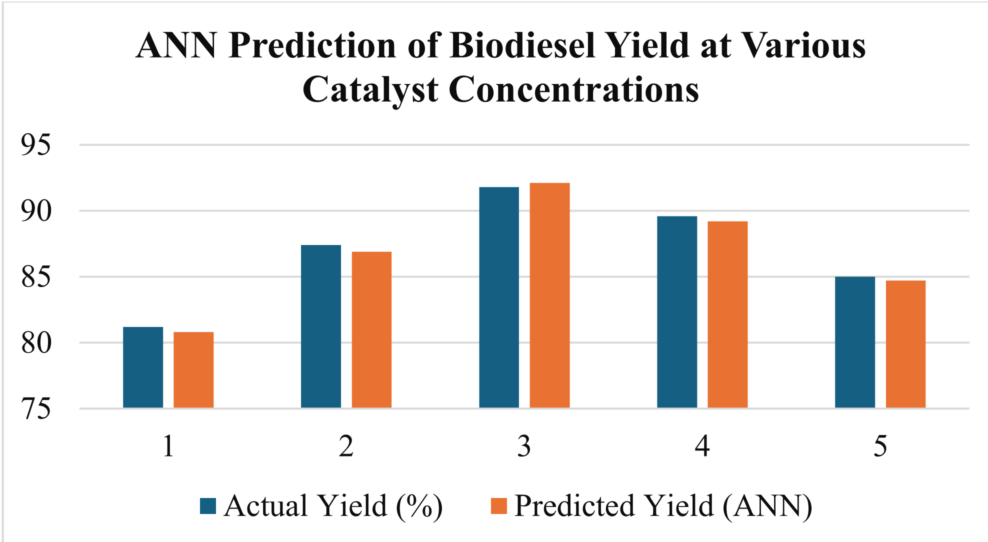

Fig.4 ANN Prediction of Biodiesel Yield at Various Catalyst Concentrations

ANN model proved to be a very accurate predictor of the catalyst concentration over the range of concentration used. The hypothetical yields were quite similar to the experimental ones, as demonstrated in Table 4, and the differences between them were always within 0.5%. As an example, the actual yield at 3% catalyst concentration was 91.8% and the ANN model had predicted 92.1%. This shows that the model is capable of capturing and replicating nonlinear trends in the reaction data. This accurate forecast proves that the model is quite strong and dependable in the optimization of biodiesel production parameters. ANN application therefore offers an effective computational tool in the prediction of results, minimizing time of experimentation and making intelligent decisions in the biodiesel process control and scale-up.

5. Conclusion

The study gives an in-depth evaluation of the performance and emission characteristics of a CI engine using different proportions of lemongrass oil-based biodiesel and diesel and a predictive analysis of the same using machine learning methods. The results show that lemongrass biodiesel has a better alternative to conventional fossil diesel because it is sustainable and efficient when blended in the right proportions. Of all the blends that were tested, B10 produced the maximum brake thermal efficiency (33.81) at full load, which means it has higher combustion efficiency, and B20 produced the minimum specific energy consumption (10.3 MJ/kWh), which means it has better fuel utilization. It was also interesting to note that B50 had the least hydrocarbon emissions (32 ppm) which supported the environmental advantages of mid-level blends. It also incorporated a model of Artificial Neural Network (ANN) to forecast biodiesel yield on the basis of catalyst concentration, and it had high accuracy with deviations always within +/- 0.5 percent of the real values. This proves the efficiency of the model in forecasting and optimization of processes. All in all, the research findings indicate that lemongrass biodiesel-diesel blends, and in particular B10, B20, and B50, could be effectively utilized in the current CI engines without the loss of performance, at the same time making a contribution to emission reduction and cleaner energy practices. The machine learning will further increase the practical relevance of this study to allow intelligent control, and efficient scaling of the biodiesel production systems.

References

1. Bitire, S.O., Nwanna, E.C., Jen, T.C., 2023. The impact of CuO nanoparticles as fuel additives in biodiesel-blend fuelled diesel engine: A review. Energy & Environment. 34(7), 2259–2289.
2. Gaur, A., Dwivedi, G., Baredar, P., Jain, S., 2022. Influence of blending additives in biodiesel on physiochemical properties, engine performance, and emission characteristics. Fuel. 321, 124072.
3. Karami, R., Hoseinpour, M., Rasul, M.G., Hassan, N.M.S., Khan, M.M.K., 2022. Exergy, energy, and emissions analyses of binary and ternary blends of seed waste biodiesel of tomato, papaya, and apricot in a diesel engine. Energy Conversion and Management: X. 16, 100288.
4. Karthickeyan, V., Ashok, B., Thiyagarajan, S., Nanthagopal, K., Geo, V.E., Dhinesh, B., 2020. Comparative analysis on the influence of antioxidants role with Pistaciakhinjuk oil biodiesel to reduce emission in diesel engine. Heat and Mass Transfer. 56, 1275–1292.

5. Kashyap, D., Das, S., Kalita, P., 2022. Influence of Oxygenated Fuel and Additives in Biofuel Run Compression Ignition Engine. Potential and Challenges of Low Carbon Fuels for Sustainable Transport. 183–243.
6. Kumar, A., Mohan, I., Lata, D.B., 2024. Modelling to predict performance and emission parameters of hydrogen, additive and nano-particles blended fuel in a dual-fuel diesel engine through artificial neural network. International Journal of Hydrogen Energy. 80, 599–611.
7. Kumar, V., Choudhary, A.K., 2023. Assessment and usability of Jatropha biodiesel blend with phenolic antioxidant to control NOx emissions of an unmodified diesel engine. Environmental Science and Pollution Research. 30(49), 108051–108066.
8. Madhu, S., Leo, G.L., Prathap, P., Devarajan, Y., Jayabal, R., 2023. Effective utilization of waste pork fat as a potential alternate fuel in CRDI research diesel engine–Waste reduction and consumption technique. Process Safety and Environmental Protection. 172, 815–824.
9. Malabadi, R.B., Kolkar, K.P., Chalannavar, R.K., 2023. Industrial Cannabis sativa: Hemp oil for biodiesel production. Magna Scientia Advanced Research and Reviews. 9(02), 022–035.
10. Malabadi, R.B., Sadiya, M.R., Kolkar, K.P., Chalannavar, R.K., 2023. Biodiesel production: An updated review of evidence. International Journal of Biological and Pharmaceutical Sciences Archive. 6(02), 110–133.
11. Mohan, I., Das, A.K., Prakash, R., Kumar, S., 2023. Prediction modeling using artificial neural network (ANN) for the performance and emission characteristics of catalytic co-pyrolytic fuel blended with diesel in a CI engine. Environmental Science and Pollution Research. 1–14.
12. Pramanik, S., 2025. Implementation of ANN and response surface method for dual-fuel CI engine optimization and prediction using water infusion and biofuel. Multimedia Tools and Applications. 1–43.
13. Sethuraman, N., Karthikeyan, D., Vinodraj, S., Thamizhvel, R., Kumarasamy, G., 2023. Performance and emission characteristics on CI engine by using waste cooking oil and waste transformer oil as substitute fuel with coconut shell as a catalyst. Materials Today: Proceedings. 72, 2469–2475.
14. Thangavelu, S.K., Ahmed, A.S., Ani, F.N., 2016. Review on bioethanol as alternative fuel for spark ignition engines. Renewable and Sustainable Energy Reviews. 56, 820–835.
15. Verma, T.N., Rajak, U., Dasore, A., Afzal, A., Manokar, A.M., Aabid, A., Baig, M., 2021. Experimental and empirical investigation of a CI engine fuelled with blends of diesel and roselle biodiesel. Scientific Reports. 11(1), 18865.