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Extraction, performance and emission characterization of diesel engine using waste lipolytic microorganism biodiesel

Arunkumar M.[1], Magesh Mani[2], Anjani Kumar Rai[3], A. Adinarayanan[4], Ram Subbiah[5], Ganeshan P.[6], Kannan S.[7], Seikh A.H.[8] and Iqbal A.[9]

[1]Department of Mechatronics Engineering, Hindusthan College of Engineering and Technology, Coimbatore, India-641032
[2]Department of Aerospace Engineering, B.S. Abdur Rahman Crescent Institute of Science and Technology, Chennai, India
[3]Department of Computer Engineering and Applications, GLA University, Mathura, Uttar Pradesh 281406, India
[4]Department of Mechanical Engineering, AMET University, Kanathur, Chennai 603112, Tamil Nadu, India
[5]Department of Mechanical Engineering, Gokaraju Rangaraju Institute of Engineering and Technology, Nizampet, Hyderabad, India
[6]Department of Mechanical Engineering, Sri Eshwar Engineering College, Coimbatore, Tamilnadu, India
[7]Department of VLSI Microelectronics, Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Chennai - 602105, Tamilnadu, India
[8]Mechanical Engineering Department, College of Engineering, King Saud University, Riyadh 11421, Saudi Arabia
[9]Department of Materials Technologies, Faculty of Materials Engineering, Silesian University of Technology, 44-100, Gliwice, Poland
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*to whom all correspondence should be addressed: e-mail: xxx
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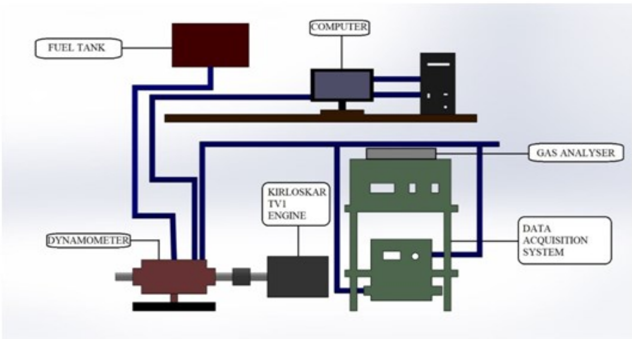
Graphical abstract



Abstract

In this study, milk wastewater will be extracted, transformed into Lipolytic microorganism's biodiesel (LMD) using transesterification, and tested for appropriateness as an alternative, sustainable, renewable source for IC engines. The properties of the created blends of biodiesel were investigated and compared to those of conventional diesel. The outcomes demonstrated that the fuel's fundamental characteristics are discussed with neat diesel. Investigated are the operation, combustion, and exhaust gas analysis of a test engine running on LMD. The studies involve running different biodiesel-diesel blends (B10, B20, B30, B40, B50, and B80) at varying loads (0, 25, 50, 75, and 100%) in a single-cylinder direct-injection diesel engine at a constant speed and comparing the results to the benchmark diesel. The values of break thermal efficiency (BTE) were decreased by 0.59, 0.68, 1.30 and 2.98% respectively for the blends of 10, 20, 30 and 50% of biodiesel mixing. The brake specific energy consumption (BSEC) is decreased by 0.1, 0.3, 0.44, and 0.77%. Any biodiesel-diesel combination reduces exhaust gas pollutants. At maximum load, the values of emissions like CO, HC, and smoke opacities of B30 decreased by 12.1%,3.94%, and 11% when compared to standard diesel. However, as per the analysis biodiesel of LMD is a potential alternative fuel that doesn't require significant alterations to be used in I.C engines.

Keywords: Biodiesel, milkwaste, fatty acids, engines, microorganisms

1. Introduction

Lipolytic microorganisms are microorganisms that are capable of producing lipases, which are enzymes that can break down fats or lipids. These microorganisms can be used in the production of biodiesel, a renewable and environmentally friendly alternative to traditional diesel fuel. The process of using lipolytic microorganisms to produce biodiesel typically involves growing the microorganisms in a suitable medium, such as a mixture of vegetable oil and water. The lipases produced by the microorganisms then break down the triglycerides in the vegetable oil into fatty acids and glycerol (Shrivastava *et al*., 2019). It is a well-known fact that the lifespan of crude oil-based fuel used in automobiles is predicted to be short given the state of our current knowledge of the use of fossil fuels and their rising rates of consumption (Hosseinzadeh-Bandbafha *et al*., 2019). Additional concerns with using diesel in an I.C engines include rising emissions of exhaust gases and the price of crude oil. Major pollutants that damage human health and contribute to environmental pollution include CO, Smoke opacity and unburned hydrocarbons. In order to address these problems and related ones, as well as prevent climate change, it is crucial to discover a suitable replacement for diesel is oil based alternative fuels (Ogunkunle and Ahmed, 2020). One such alternative fuel that is produced by the transesterification process from plant biomass or seeds is biodiesel. With or without engine modifications, biodiesel, a renewable fuel that is free of petroleum, can be used in diesel engines. The percentage of biofuel used in the industry of automotive is rising quickly in the twenty-first century due to concerns about the environment, society, and economy (Shrivastava *et al*., 2020).

As a substitute for fossil fuels, various biodiesels have been used in ICE to produce electricity. The manufacturing of biodiesel uses a variety of vegetable oils, both edible and non-edible. The characteristics of an IC engine running on enhanced waste-source fuel were examined in terms of combustion, performance, and exhaust pollutants in various countries (Munimathan *et al*., 2021). Upgraded cooking oil waste outperformed standard diesel in terms of power and torque by 14% and 13.8%, respectively. Fuel produced by the disposal of waste plastic least NOx during combustion because of the low-pressure curve. biodiesel and neem oil its mixes were used instead of diesel on the performance of diesel engines (Al-Dawody and Edam, 2022). Using a neem oil biodiesel blend of B20 and diesel, this study found that the BTE of diesel engines produced values that were substantially identical to each other. Investigation of the performance, financial evaluation, and emission analysis of Moringa oleifera and Jatropha curcas methyl ester fuel blends in a diesel engine with only one cylinder (Karthickeyan, 2020). Rapeseed oil blends' BSFC and BSEC are marginally greater than those of pure ordinary diesel. Lesser loading levels resulted in the lower blends having better beginning characteristics (Murali *et al*., 2020). Peak cylinder pressure and heat release rate increased at low engine loads but were almost the same at high engine loads. Rapeseed oil can be substituted for up to 20% of the diesel fuel in diesel engines using biodiesel modifying engines, according to the study's findings (Katekaew *et al*., 2021). This reduces the viscosity of the fuel. To analyse the efficiency of diesel engines, investigation on jojoba oil biodiesel was conducted. It was found that, as the load was increased, B20 is undergoing reducing tendency in emissions, as well as highest BTE content for various blends were tested (Gowda *et al*., 2021). With the use of hybrid bio-diesel blends based on cardanol, various studied the efficiency. The outcomes showed that hybrid biodiesel's brake thermal efficiency was approximately equal to diesel's at full load (Akcay and Ozer, 2019). The Rapeseed methyl ester's efficiency and exhaust emissions were improved with the use of additives like hexane and hexadecane. It was claimed that the reduction of hazardous gases from exhaust gas results from the addition of additives to biodiesel (Sathish *et al*., 2022).

Heat release rate and thermal efficiency both experienced significant improvements. Investigation and the exhaust parameter of agricultural engines running on biodiesels of coconut oil. Many studys demonstrated biodiesel made the direct use of coconut acid oil in diesel engines without requiring any changes (Doppalapudi *et al*., 2023). The engine's performance was somewhat enhanced by using these biodiesels, but brake-specific fuel consumption (BSFC) went up. Accordingly algal biodiesel/diesel/n-pentane blends improved DI diesel's efficiency, combustion, and emissions engines. Using a mixture of 50% normal biodiesel and 50% algal biodiesel. n-pentane was employed to improve the engine's performance (Bitire *et al*., 2022; Sundar *et al*., 2022; Kumar *et al*., 2023; Alok *et al*., 2022). It was found that the engine performance of a biodiesel blend that includes n-pentane is much greater than that of ordinary diesel. When utilising biodiesel as an alternate fuel with heated Dhupa seed oil, various studied the operation, emissions, and combustion of a CI engine (Jain and Vora, 2021). The results of this study showed that preheating blends improves fuel spray characteristics by reducing viscosity, which boosts engine performance while reducing CO and HC emissions while slightly raising NOX and CO2 emissions (Elumalai *et al*., 2021). A single-cylinder diesel engine driven by dual fuels was the subject of research in terms of performance and emission characteristics. The results of this investigation showed that the use of turpentine oil and Jatropha biodiesel produced good performance and reduced emissions while raising HC emissions (Sharma and Sharma, 2021).

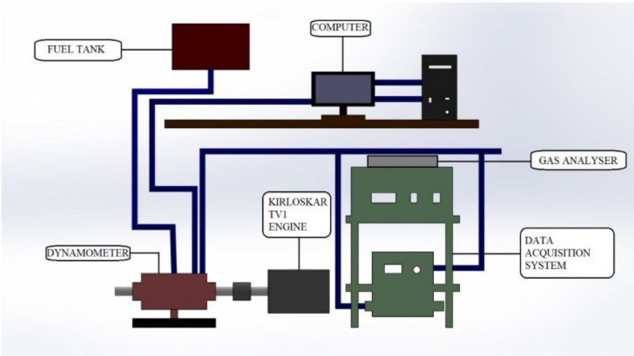


Figure 1. Schematic diagram

Figure 2. Experimental setup

This study established that the viscosity of the biodiesel is reduced, and the cylinder pressure is increased when bioethanol is added to cotton and canola biodiesel (Tamilvanan *et al*., 2021). It was also determined that adding bioethanol to a particular type of biodiesel reduces NOx. In a diesel engine, it was examined that the various parameter of engine and property using diesel with neem oil biodiesel (Arunkumar *et al*., 2019). This study showed that, in addition to having positive effects on the environment, using methyl ester of neem oil is improving harvesting and reduce the unpredictability of fuel supply. The study findings can suggest biodiesel from neem seed is a substitute for conventional diesel in diesel engines is a practical option (Bitire *et al*., 2022; Sakthi Rajan and Muralidharan, 2021). The engine's performance in this investigation was enhanced. One method for increasing performance and lowering while usage, NOx emissions biodiesel in an engine is to use additives. Overall, it has been found that biodiesel produced from biomass, plant seeds, or vegetables can be used as a sustainable alternative source for I.C engines (Mehmet *et al*., 2020; Ramshankar *et al*., 2023). According to the extensive literature cited above, researchers are making systematic attempts to make biodiesel from a range of oilseeds and to improve its functionality by adding additives. Some of the biodiesel that was examined was made from edible oils, while other samples were from non-edible oils (BhanuTeja *et al*., 2022; Sureshbabu *et al*., 2023) Because make food scarce, edible vegetable oils should be used as little as possible. Non-edible vegetable oils should also contribute less because their cultivation requires land facilities. Analysing every viable alternative energy source could also help with climate change mitigation, adaptation to rising energy demand, and effective resource usage. As a result, this study suggests producing utilising milk wastewater from milk industry as a source of biodiesel a substitute in a diesel engine.

2. Experimental conditions and methods

The Kirloskar TV1 one cylinder, 4- stroke, vertical-cylinder engine is employed in this experiment. To alter the load on the engine, an eddy current dynamometer is linked to it which was show in Figure 2 experimental setup. A schematic of the entire setup can be seen in given Figure 1 provides a visual representation of the experimental setup and Table 1 contains the engine specifications. Data from the trials has been archived using a data acquisition system (DAS), which records the data using "Engine Soft" software. A hundred cycles have been averaged for each experiment to determine a crank angle and the difference in in-cylinder pressure. During the investigation, both the engine fuel consumption and the percentage of brake power loading are measured.
The AVL gas analyser was used to evaluate the exhaust gas pollutants, including NOx, HC, CO, and CO2.

Table 1. Specifications of test engine

Manufacturer	Kirloskar
Model	TV1
Type of engine	Four stroke vertical single cylinder CI engine.
Displacement	661 cc
Max brake power	5.2 kW
Speed	1500 rpm
CR	17.5:1
Lubrication system	Forced feed system
Bore and stroke	87.5 x 110 mm
Method of cooling	Water cooled
Fly wheel diameter	1262 mm
Injection pressure	200 bar

3. Production of biodiesel

According to the calculations described above, LMD oil's FFA was discovered to be 21%. The amount of FFA in produced LMD oil is greater. Because of this, the production of biodiesel involves two steps: acid esterification and base transesterification.

3.1. Base transesterification

transesterification is the process by which biodiesel is produced from vegetable oil or animal fat. it involves the reaction of a triglyceride (such as lipolytic microorganism's) with an alcohol (such as methanol or ethanol) in the presence of a catalyst (usually sodium hydroxide or potassium hydroxide) to form esters (biodiesel) and glycerol.

The chemical reaction for the transesterification of a triglyceride with an alcohol can be written as follows:

Triglyceride + Alcohol ⇌ Biodiesel + Glycerol

The reaction is reversible, meaning that both the reactants and the products can be converted back and forth. Therefore, to drive the reaction towards the formation of biodiesel, excess alcohol is usually added to the reaction mixture.

One litre of CH oil is converted to diglyceride, which is then heated to 64 °C and sends to the conical flask reactor. In the interim, a methoxide combination was made according to the diglyceride's new FFA value. To make the methoxide solution, dissolve 3.5 +/- FFA grammes of methanol in 300 mL with a pellet of sodium hydroxide (NaOH). When the heating oil reached 64 degrees Celsius, the methoxide solution was added to it. In order to obtain a homogenous mixture, then it was maintained at 68 °C for two hours while being stirred constantly at 700 rpm. After that it was continuously heating normally and mixing with the use of magnetic stirrer for two hours, then the liquid is transferred to a separate funnel and held there for another two hours. After that the methyl ester biodiesel separated at the top layer and the Black glycerol separated at the flask's bottom. Glycerol was drained and stored separately in a 300 mL container. Through this transesterification procedure, LMD oil is ultimately converted to LMD oil methyl ester (LMD) biodiesel. The surplus methanol concentration in the LMD biodiesel was evaporated by heating it to 70 °C. The properties of the diesel and mixing of LMD is tabulated in Table 2.

Transesterification is a widely used method for producing biodiesel, and it is a relatively simple process that can be performed on a small scale or large scale, depending on the intended use.

Table 2. Properties of diesel and biodiesel

Properties	Diesel	B10	B20	B30	B40	B50	B80
Cetane no	48	48.8	49.6	50.4	51.2	51.7	52
Specific gravity	0.83	0.84	0.85	0.86	0.87	0.879	0.8802
Viscosity @ 40^{o}C	3.9	4.16	4.412	4.668	4.924	4.98	5.18
Calorific value (kJ/Kg)	44000	41600	40360	39040	37720	37520	36400
Density (kg/m^3)	830	841	849	859.2	874	873	878.2
Flash point (^{O}C)	56	58	62	66	70	72	76
Fire point (^{O}C)	62	67	73.5	79.2	85.3	86.2	92

Table 3. uncertainty values

Parameters	Systematic Errors (±)
Speed	1 ± rpm
Load	± 0.1 N
Time	± 0.1 s
Brake power	± 0.15 kW
Temperature	± 1°
Pressure	± 1 bar
NO_x	± 10 PPM
CO	± 0.02%
CO2	± 0.02%
HC	± 12 PPM
Smoke	± 1 HSU

4. Analysis of uncertainty

Due to a variety of factors, including equipment selection, calibration, accuracy, observations, climatic conditions, etc., uncertainty may occur during the experiment. Table 3 contains a list of all the instruments' uncertainties that were used to measure various parameters. The total instrument uncertainty was calculated to be 2.75%.

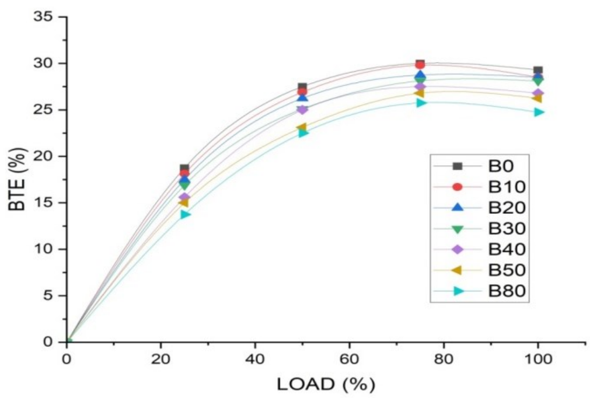


Figure 3. BTE Vs Load

5. Engine performance evaluation

Engine performance evaluation typically involves measuring and analyzing various aspects of an engine's performance, such as of BSEC and BTE, fuel efficiency, emissions, and other related factors utilising LMD biodiesel as an alternative fuel and standard diesel as a baseline while altering the engine's load. This information can be used to improve the engine's design, optimize its operation, or assess its overall efficiency and reliability.

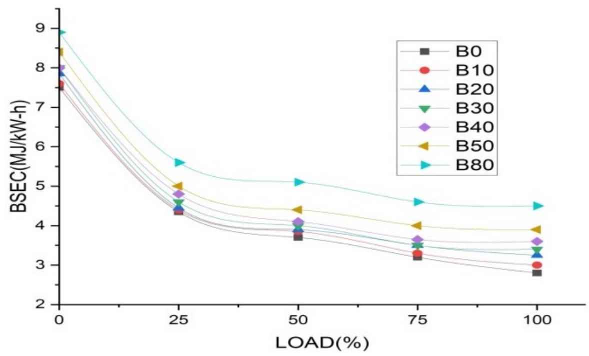


Figure 4. BSEC Vs Load

5.1. Brake thermal efficiency

The efficiency of BTE for various blend show that more similar value except B10, B20 and B30 respectively. In comparison to B0, B20, and B30, B40, B50, and B80 have substantially lower BTEs. At full load conditions the blending of LMD and diesel produces 30.5%, 30.2%, 30%, 29.3%, 28.5%, 26% for the blending ratio of B0, 10, 20, 30, 40,50 and 80 respectively. LMD biodiesel BTE shows potential for use as a suitable alternative fuel in diesel engine. All graphs' trends follow predictable patterns, as can be seen in the Figure 3. Due to the fact that BTE is a function involving mass flow of fuel used by the brake power, BTE decreases as the proportion of LMD biodiesel in the blend rises.

5.2. Brake specific energy consumptions

It is made up of the BSFC plus the calorific value of the fuel. It computes the amount of energy necessary to produce a unit power output over the course of an hour. As energy efficiency improves, BSEC frequently declines. The BSEC of conventional diesel is shown in Figure 4. Alongside the BSEC of diesel with LMD biodiesel blended under various loading situations of engine.

As BSEC is a function of calorific value fuel mass and flow as measured by brake power, it decreases with increasing load. Because biodiesel has a slower rate of heating and a higher mass flow of fuel, BSEC rises as the proportion of LMD biodiesel in the blend increases. Because of biodiesel characteristics, the BSEC of B10, B20, and B30 is lower than that of B40, B50, and significantly lower than that of B80.At full load conditions the values of BSEC for B0, B10, B20, B30, B40, and B50 is 2.66, 2.86, 3.15, 3.25, 3.36, 3.76, and 4.12 MJ/kWh, respectively. It was found similar outcomes on engines fueled with diesel blends and eucalyptus oil, and also it was found similar outcomes on engines fueled with the blends of Jatropha biodiesel oil.

6. Features of exhaust gas emissions

Exhaust gas emissions refer to the gases like CO, CO_2, HC, NO_X that are released from the exhaust system of IC engines. These emissions are a major contributor to air pollution and have negative impacts on human health and the environment.

6.1. NO_x emissions

When O_2 and N_2 like molecules interact with each other at high temperatures forms an exhaust gas component NOx. The interaction takes place inside the cylinder of engine. The NOx exhaust properties of LMD blends and normal fuel are shown in Figure 5 at various engine loading situations.

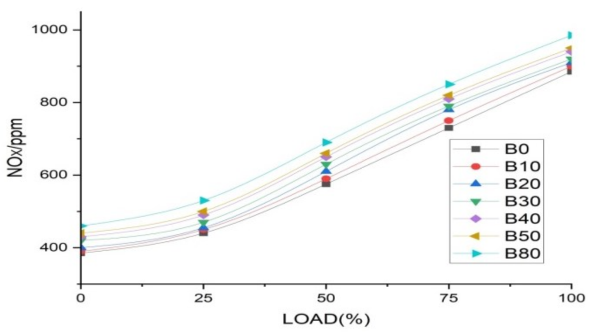


Figure 5. NOx Vs Load

The Figure 5 shows the fluctuation in HC emission concentrations in emission gas for various blends of LMD biodiesel and normal diesel under situations of various loading of engine. How much NOx emission is produced depends significantly on the temperature-specific stoichiometry of the mixture, the reaction duration and the amount of O2 in the mixture. As the engine's workload grows, so does the NOx emission in the exhaust gas.

This is because a larger amount of fuel is injected with a faster response time, resulting in a higher injection pressure that raises the temperature inside the combustion chamber. The Figure 5 shows that the emission of NOx from LMD is consistently increasing than that of conventional diesel. The reason may be ignition delay and delivery of more fuel to the combustion chamber, which would raise the cylinder pressure and combustion chamber temperature. The graphic shows that as the blend's LMD biodiesel content rises, so do the NOx emissions. This is due to biodiesels' quick ignition time, inherent oxygen content, and higher fuel injection volume owing to their density increasing and less calorific value. All of these elements raise the temperature inside the cylinder, which increases NOx generation. The emission of NOx for B10 to B80 at full load condition with LMD is 1.6%, 3.1%, 3.7%, 4.8%, 5.6%, 7.0%.

6.2. Emission of HC

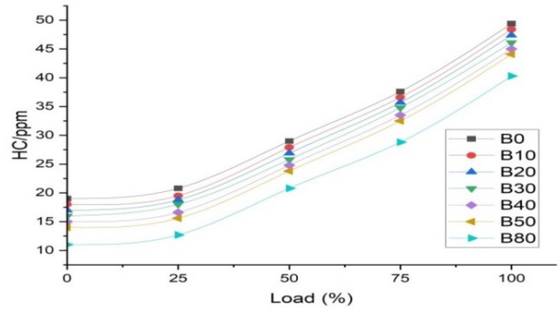


Figure 6. HC Vs Load

The emission of HC is also an important parameter at the time of analysing emission performance. The Figure 6 shows that the increase in tendency of HC while using LMD biodiesel when compared to normal diesel fuel. It is noted that the emission of HC is decreased by 40% and 19% for the blending ratio of B80 when compared to B0 at full load conditions.

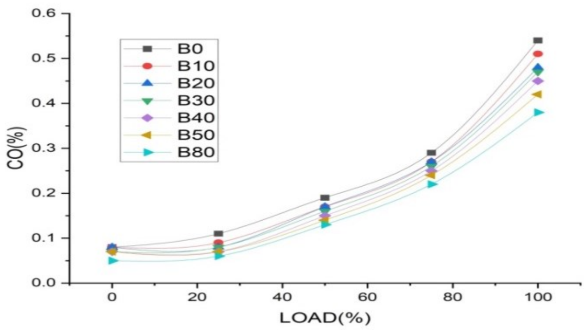


Figure 7. CO Vs Load

6.3. Emissions of CO

As engine loading increases the emissions of CO also increases. This is because of increasing of load, the amount of oxygen in the combustion chamber decreases. Measurements are made of the CO content of the LMD biodiesel exhaust gas. At 1500 rpm, CO emission is shown in the Figure 7 against engine load

There is a decrease in tendency in CO emission for all the blending ratios of LMD biodiesel which having intrinsic O_2 and leads to the sequential change from CO to CO_2 throughout the engine operation.

6.4. Emissions of CO_2

The Figure 8 shows the differences in CO_2 emissions under various engine loading scenarios. According to the quantity of CO_2 in the exhaust fumes, the gasoline was burned properly. Complete combustion inevitably produces CO_2, which is a main resource of air pollution which amplifies the impact of greenhouse effect. This is so because the components of biodiesel are higher in oxygen than conventional diesel. There is reducing tendency of CO_2 emission for normal diesel fuels than that of blending of LMD biodiesel. The increasing of CO_2 will happen if blending of biodiesel and changing of load conditions changes as well. In comparison to ordinary diesel, CO_2 emissions were increased for various proportions of biodiesel with diesel by 0.31%, 0.76%, 1.23%, 1.2%, 1.8%, and 3.5% respectively. This might be because CO is converted to CO_2 during burning. In this experiment, at all loading settings and blending ratios, CO is inversely proportional to CO_2. This might be because CO is converted to CO_2 during burning when the amount of oxygen inside the combustion chamber rises.

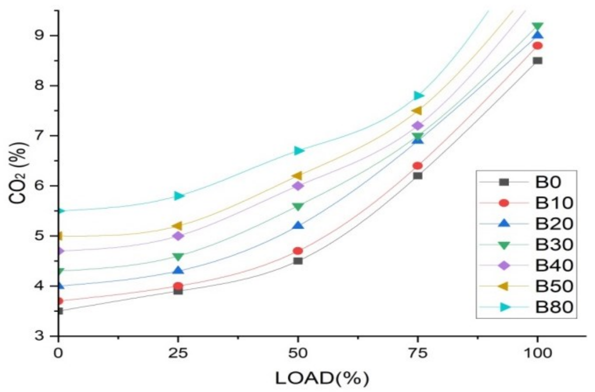


Figure 8. CO_2 Vs Load

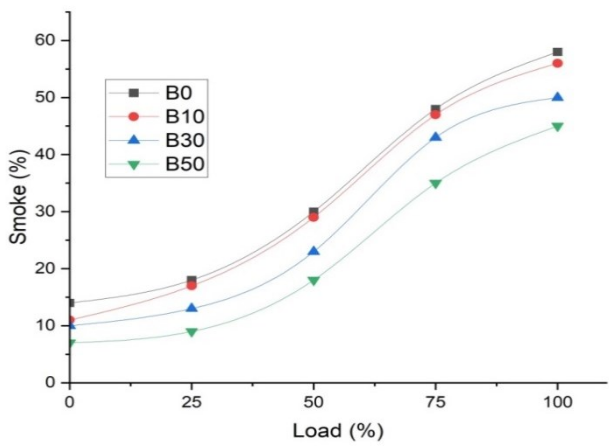


Figure 9. Smoke Vs Load

6.5. Opacity of smoke

Because of incomplete combustion, a lack of oxygen, self-ignition, and fuel atomization, smoke opacity forms in the exhaust gas. Figure 9 contrasts the smoke opacity of pure diesel and LMD biodiesel blends. As the load on the engine increases, the smoke's opacity rises. When the load rises, more fuel is pumped for a given volume of air, which results in a slower oxidation process and higher smoke production. Due to inherited oxygen, LMD biodiesel and all of its mixes emit less opaque smoke than normal diesel. The extra oxygen in LMD biodiesel and its blends speeds up combustion and reduces smoke emissions. B10, B30, and B50 each have a 3.35%, 11.5%, and 17.67% reduction in smoke opacity, respectively. A direct injection diesel engine using oil made from pyrolyzed Jatropha biomass and solar power displayed the same tendencies.

7. Conclusion

The study examines the impact of unique LMD biodiesel on the operation, combustion, and emission characteristics of the engine. Kirloskar's TV- The experiment makes use of a single direct-injection diesel engine and an eddy current dynamometer. Throughout the investigation, the following significant details were noticed

• The converting of LM wastewater to LMD by using the transesterification process. It is possible to convert 0.7 Lit of biodiesel from 1 lit of LMD. • The newly discovered LMD biodiesel's viscosity and fire point are decreased, also there is increasing tendency in calorific value, by mixing it with conventional diesel at various blending ratios. As a result, ICE engines can use LMD biodiesel blends as an alternative fuel without requiring any engine modifications.

• When compared to ordinary diesel, BTE results for all tested fuels are satisfactory. The value of BTE are decreased by 0.59, 0.62 & 1.2% for various blending ratios of biodiesel at full, load condition.

• The value of BSEC was reduced for upto 30% of biodiesel mixing with diesel, indicating that these blends should be utilised rather than other mixes.

• Lower blends (B10 to B30), as measured by NHRR and pressure of the cylinder for LMD, produce superior results in combustion engine analysis.

• When compared to conventional diesel, the evaluated LMD's emission parameters perform good. The value of HC, CO & smoke are reduced upto 8.69 &14.03% respectively. Overall, it was discovered through this experimental study that the newly produced LMD biodiesel can be utilised in ICEs up to 30% of the time without significantly altering the engine. Overall, it was discovered through this experimental study that the newly produced LMD biodiesel can be utilised in ICEs up to 30% of the time without significantly altering the engine. Using lipolytic microorganisms to produce biodiesel has several advantages over traditional methods, including the use of renewable resources and the potential for lower production costs. Additionally, lipolytic microorganisms can be grown using a variety of waste materials, such as restaurant grease, which can help reduce waste and pollution.

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References

Aatmesh J. and Vora K. (2021). Quality Biodiesel Production and Engine Performance & Emission Evaluation Using Blends of Castor Biodiesel. No. 2021-28-0001. *SAE Technical Paper*, 2021.

Akcay M. and Ozer S. (2019). Experimental investigation on performance and emission characteristics of a CI diesel engine fueled with fusel oil/diesel fuel blends. Energy Sources, Part A: *Recovery, Utilization, and Environmental Effects*, 1–16.

Al-Dawody M.F. and Edam M.S. (2022). Experimental and numerical investigation of adding castor methyl ester and alumina nanoparticles on performance and emissions of a diesel engine. *Fuel*, **307**, 121784.

Arunkumar M., Kannan M. and Murali G. (2019). Experimental studies on engine performance and emission characteristics using castor biodiesel as fuel in CI engine. *Renewable Energy*, **131**, 737–744.

Ayyasamy T., Balamurugan K., Ashok B., Selvakumar P., Dhamotharan S., Bharathiraja M. and Karthickeyan V. (2021). Effect of diethyl ether and ethanol as an oxygenated additive on Calophyllum inophyllum biodiesel in CI engine. *Environmental Science and Pollution Research,* **28** (2021): 33880–33898.

BhanuTeja N., Ganeshan P., Mohanavel V., Karthick A. Raja K., Krishnasamy K. and Muhibbullah M. (2022). Performance and Emission Analysis of Watermelon Seed Oil Methyl Ester and n-Butanol Blends Fueled Diesel Engine, Mathematical Problems in Engineering, Article ID 2456338, **12**, 2022. https://doi.org/10.1155/2022/2456338

Bitire S.O. and Jen T.C.. (2022). The impact of process parameters on the responses of a diesel engine running on biodiesel-diesel blend: An optimization study. *Egyptian Journal of Petroleum*, **31(**3), 11–19.

Bitire, S.O., and Jen T.C. (2022). The impact of process parameters on the responses of a diesel engine running on biodiesel-diesel blend: An optimization study. *Egyptian Journal of Petroleum*, 31(3), 11–19.

Doppalapudi A.T., Azad A.K. and Khan M.M.K. (2023). Advanced strategies to reduce harmful nitrogen-oxide emissions from biodiesel fueled engine. *Renewable and Sustainable Energy Reviews*, **174**, 113123.

Elumalai P.V., Sivakandhan C., Parthasarathy M., Iqbal S.M. and Arunkumar M. (2021). Investigation on the mitigation of environmental harmful emissions by incorporating nanoparticles to biofuel water nano emulsion in low heat rejection engine. *Heat and Mass Transfer*, **57**, 1235–1250.

Gowda S.H., Avinash A. and Raju K. (2021). Production optimization of Vateria Indica biodiesel and performance evaluation of its blends on compression ignition engine. *Sustainable Chemistry and Pharmacy*, **22**, 100475.

Hosseinzadeh-Bandbafha H., Khalife E., Tabatabaei M., Aghbashlo M., Khanali M., Mohammadi P., Shojaei T.R. and Salman S. (2019). Effects of aqueous carbon nanoparticles as a novel nanoadditive in water-emulsified diesel/biodiesel blends on performance and emissions parameters of a diesel engine. *Energy Conversion and Management*, **196**, 1153–1166.

Karthickeyan V. (2020). Experimental investigation on combined effect of ignition promoters and ceramic coating fuelled with papaya seed oil methyl ester in DI diesel engine. *Renewable Energy*, **148** (2020), 772–789.

Katekaew S., Suiuay C., Senawong K., Seithtanabutara V., Intravised K. and Laloon K. (2021). Optimization of performance and exhaust emissions of single-cylinder diesel engines fueled by blending diesel-like fuel from Yang-hard resin with waste cooking oil biodiesel via response surface methodology. *Fuel*, **304**, 121434.

Kumar S.C., Thakur A.K., Raj R.A.J.J. and Natarajan S.K. (2022). An experimental investigation on the effects of magnesia and alumina nano additives on the exhaust emissions and performance of CI engine using spirulina microalgae biodiesel. *Environmental Science and Pollution Research*, 1–11.

Mehmet A., Yilmaz I.T. and Feyzioglu A. (2020). Effect of hydrogen addition on performance and emission characteristics of a common-rail CI engine fueled with diesel/waste cooking oil biodiesel blends. *Energy*, **212**, 118538.

Munimathan A., Mohanavel V., Afzal A., Sathish T., Ravichandran M., Khan S.A., Abdullah N., Azami M.H.B. and Asif M.A. (2021). study on performance and emission characteristics of diesel engine using Ricinus Communis (castor oil) ethyl esters. *Energies*, **14(**14), 4320.

Murali G., Anusha M. and Arunkumar M. (2020). Performance study of a single cylinder diesel engine using diesel with Pongamia pinnata and Camelina sativa seed oil blends. *Materials Today, Proceedings*, **21**, 206–211.

Ogunkunle O. and Ahmed N.A. (2020). Exhaust emissions and engine performance analysis of a marine diesel engine fuelledwith Parinari polyandra biodiesel–diesel blends. *Energy Reports*, **6**, 2999–3007.

Pankaj S., Salam S., Verma T.N. and Samuel O.D. (2020). Experimental and empirical analysis of an IC engine operating with ternary blends of diesel, karanja and roselle biodiesel. *Fuel*, **262**, 116608.

Pankaj S., Verma T.N. and Pugazhendhi A.. (2019). An experimental evaluation of engine performance and emisssion characteristics of CI engine operated with Roselle and Karanja biodiesel. *Fuel* **254**, 115652.

Patel A., Sharma A.K., Rova U., Christakopoulos P. and Matsakas L. (2022). In-depth analysis of waste cooking oil as renewable and ecofriendly biofuel candidate. *In Waste-to-Energy Approaches Towards Zero Waste*, 87–103. Elsevier, 2022.

Prabhakar S. and Sharma A.K. (2021). Application of response surface methodology for optimization of fuel injection parameters of a dual fuel engine fuelled with producer gas-biodiesel blends. Energy Sources, Part A: Recovery, *Utilization, and Environmental Effects*, 1–18.

Ramshankar P., Sashikkumar M., Ganeshan P., Raja K. (2023). Experimental investigation of hybrid composites using biowastes and Calotropis gigantean, an eco-friendly approach, *Global NEST Journal*, 25(4), 70–76

Sakthi Rajan C. and Muralidharan K. (2021). Effects of partially stabilized zirconia fueled with Borassus biofuel at different piston bowl geometries in LHR engine. *Journal of Thermal Analysis and Calorimetry*, 1–17.

Sathish T., Mohanavel V., Arunkumar M., Rajan K., Soudagar M.E.M., Mujtaba M.A., Salmen S.H., Al Obaid S., Fayaz H., Sivakumar S. (2022). Utilization of Azadirachta indica biodiesel, ethanol and diesel blends for diesel engine applications with engine emission profile, *Fuel*, **319**, 123798.

Sundar S.P., Vijayabalan P., Kaliappan V.K., Sathyamurthy R., Kabeel A.E. and Kamalakkannan K. (2022). Emission reduction and performance enhancement of diesel engine fuelled using palm oil biodiesel and nanoparticle as additive. *Environment, Development and Sustainability*, 1–20.

Sureshbabu Y., Ganeshan P., Raja K. and Vivek S. (2023). 3Performance and emissions parameters optimization of thermal barrier coated engine tested with Tamanu blended diesel fuel: a novel emission pollution-preventive approach, *Global NEST Journal*, **25**(3), 78–86