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PERFORMANCE AND EMISSION CHARACTERISTICS OF RAPHANUS SATIVUS, JATROPHA, AND BALANITES AEGYPTIACA SEED MIXED BIODIESEL BLENDS IN A DIRECT INJECTION DIESEL ENGINE

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Abstract

The current study analyzes the performance and emission attributes of different blends (0%, 20%, 40%, 60%, 80%, and 100% being termed as MB0, MB20, MB40, MB60, MB80 and MB100, respectively) of biodiesel derived from Raphanus sativus, Jatropha, and Balanites aegyptiaca seeds with conventional diesel. The MB0 blend was pure diesel, and the MB100 blend was pure biodiesel (with no diesel). Critical performance parameters like Brake Thermal Efficiency (BTE), Brake Specific Fuel Consumption (BSFC), and Exhaust Gas Temperature (EGT) were evaluated experimentally. Moreover, the environmental effects were assessed by measuring emission characteristics such as Carbon Monoxide (CO), Hydrocarbons (HC), Nitrogen Oxides (NO_x), and Smoke Opacity. The results indicated that the mixed biodiesel blend MB20 exhibited a higher BSFC by 5.08% and a lower BTE by 3.13% compared to diesel at maximum load. The emission characteristics are much better performed by MB20 when compared with diesel.

Additionally, the study examined the influence of diethyl ether as an oxygenated additive on the targeted biodiesel blend. The improved biodiesel blend (MB20) was blended with 5%, 10%, and 15% DEE, and MB95E5, MB90E10, and MB85E15 were prepared. Incorporating diethyl ether dramatically changed combustion behavior. The performance and emission characteristics were substantially changed. The results are presented and discussed here.

Keywords: Raphanus sativus seeds, Jatropha-Castor seeds, Waste Balanites aegyptiaca seeds, Diethyl Ether.

1. Introduction

Driven by growing global concerns about energy security and environmental sustainability, the search for alternative fuel sources has been accelerated. The burning of fossil fuels is a major source of greenhouse gases that escape into the atmosphere, causing climate change and associated degradation. As a renewable energy source that can be made from various feedstocks and does not require modification of existing diesel engines, biodiesel has been recognized as a viable alternative. Yet the decision on an appropriate feedstock is critical for it to be sustainable and economically viable. This study investigates the production of biodiesel from seeds of Raphanus sativus (oilseed radish), Jatropha-Castor, and Balanites aegyptiaca (desert date) based on their high oil content, non-food status, and ability to reduce dependency on fossil fuels [1], [2], [3].

Raphanus sativus, Jatropha, and Balanites aegyptiaca are selected as biodiesel feedstocks due to their sustainability and availability. Biodiesel feedstocks based on edible oils like soybean and sunflower have raised concerns about food security, driving a transition to using non-edible alternatives. Raphanus sativus, typically cultivated as a cover plant with excellent oil content and low agricultural input requirements, appears to be a suitable substrate for biodiesel synthesis [1], [2]. Jatropha oils have been examined in detail for biodiesel purposes due to their high viscosity and good lubricating qualities. Although Jatropha is drought-resistant and gives a high oil yield, its high NO_x emission makes blending it with castor oil necessary to achieve better combustion characteristics [4], [5]. Balanites aegyptiaca is a non-edible feedstock growing in arid regions and saline soils, providing a sustainable biodiesel feedstock with desirable oil characteristics [6].

Formulated biodiesel from a blend of feedstocks includes mix-matching to overcome challenges widespread for single-feedstock biodiesel, including oxidative stability, viscosity, cold flow properties, and emissions. Jatropha, Castor, and Balanites oils blend ensures suitable viscosity, density, and calorific value balance, improving biodiesel fuel properties [3], [6]. Moreover, the high NO_x emissions of Jatropha biodiesel can also be reduced by blending with Castor and Balanites oils, which contain different fatty acid compositions to minimize nitrogen oxide formation [7]. This improves oxidative stability, ensuring a better shelf life for the fuel and minimizing polymerization during the storage process [6].

Biodiesel production is considered economically viable only if reasonably cheap feedstocks supplement it. Using several non-edible oil-originated resources grown in degraded land minimizes competition with food crops and makes biodiesel production economically feasible [8]. Furthermore, these crops can be grown in non-arable areas for typical food crops, thus providing rural employment and optimizing land utilization for biofuel production [9].

Vegetable oils are noted for being renewable, widely available, biodegradable, non-toxic, and environmentally friendly fuels. Biodiesel, closely resembling diesel, can enhance its performance and emission characteristics by reducing viscosity by adding oxygenated additives. Bhupesh Sahu et al. [10] performed experiments with a CI engine using Jatropha oil and showed decreased brake thermal efficiency and increased brake-specific fuel consumption. Emissions results included reduced CO, HC, smoke opacity, and increased CO2 and NOx. Abed et al. [11] performed experiments on a diesel engine, using biodiesel blends (Jatropha, palm, algae), which showed lower CO, HC, CO2, and smoke emissions at B10 and B20 levels compared to diesel, but all blends of biodiesel exhibited more significant NOx emissions than diesel fuel.

Deepak Agarwal et al. [12] study focuses taking place on performance comparisons of biodiesel blends with neat diesel, including prolonged service analysis for exhaust emissions and computational performance parameter extrapolation, aiming to propose design changes based on prolonged engine service with alternate fuels.

From the above literature, it can be concluded that limited work is available on mixed biodiesel (Raphanus sativus, Jatropha, and Balanites aegyptiaca) used in diesel engines. So, the current study is intended to fill this gap. In the current study, six different variations of fuels are being used to test diesel engines' emission and performance characteristics. The three fuels viz. Raphanus sativus, Jatropha, and Balanites aegyptiaca are blended with diesel in equal proportions to get six different blends: 0%, 20%, 40%, 60%, 80%, and 100%. Here, 0% is pure diesel fuel, and 100% is pure biodiesel (a mixture of Raphanus sativus, Jatropha, and Balanites aegyptiaca fuel). The names given to these fuels are MB0, MB20, MB40, MB60, MB80 and MB100 respectively. An additional was conducted to examine the influence of diethyl ether as an oxygenated additive on the targeted biodiesel blend. The improved biodiesel blend (MB20) was blended with 5%, 10%, and 15% diethyl ether, and MB95E5, MB90E10, and MB85E15 were prepared and compared with pure diesel.

2. Materials and Methods

2.1 Materials

Figures 1, 2, and 3 depict the seeds of Raphanus sativus, Jatropha-Castor, and Balanites aegyptiaca, respectively. Raphanus sativus trees are grown in Southeast Asia, while Jatropha-Castor trees are commonly cultivated in India, Brazil, and Argentina. Balanites aegyptiaca, known as desert plants, are found in Africa, the Middle East, and the Indian subcontinent.

Figure 1 (a) Raphanus Sativus Seeds (b) Jatropha Seeds (c) Balanites Aegyptiaca Seeds

The primary use of these trees is in medicine; for instance, Raphanus sativus seeds are utilized for cancer prevention. Additionally, they produce biofuels that can be mixed with diesel.

2.2 Transesterification process

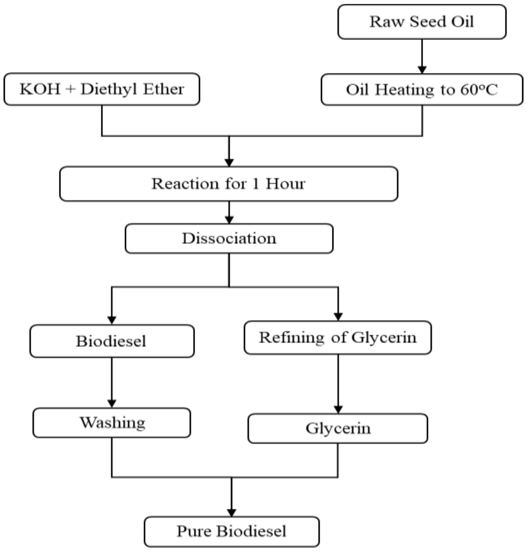

Fig. 2 Flow chart of the transesterification process followed to produce the biodiesels

2.3 Transesterification

2.3.1 Feedstock Selection and Preparation

The biodiesel utilized in this research was produced from three non-food oil sources: Raphanus sativus (oilseed radish), Jatropha curcas, and Balanites aegyptiaca. The oils were recovered from seeds sourced from authenticated sources, mechanically pressed, and solvent-extracted to produce high oil content. The recovered oils were subjected to acid value, viscosity, density, and fatty acid analysis before transesterification.

A two-stage transesterification process was applied to produce biodiesel because the seed oils had a high content of free fatty acids (FFA).

2.3.2 Acid Pre-treatment

To lower the FFA content to less than 1%, methanol (CH_3OH) and sulfuric acid (H_2SO_4, 1% v/v) were added in a molar ratio of 6:1 (methanol to oil). The combination was stirred at 60°C for 1 hour. The treated oil was subsequently separated and neutralized before the following process.

2.3.3 Base-Catalyzed Transesterification

The pre-treated oil was blended with methanol (6:1 molar ratio) and potassium hydroxide (KOH, 0.5% w/w catalyst). The reaction was performed at 60–65°C for 60 minutes under continuous stirring (300 rpm). The reaction mixture was left to settle for 12 hours after completion to separate the glycerol phase. The biodiesel layer was washed thrice with warm distilled water (50°C) to remove glycerol and residual catalyst. The resultant biodiesel was dried at 110°C for 1 hour to evaporate any trace of moisture.

Individual transesterification of each of the three oils (Raphanus sativus, Jatropha curcas, and Balanites aegyptiaca) was done as per the above procedure.

2.4 Biodiesel Blending

Following individual transesterification, the three samples of biodiesel were mixed in equal volumes to get MB0, MB20, MB40, MB60, MB80 and MB100 biodiesels, where MB0 is pure diesel, MB20 indicates 20% of the mixture of three biodiesels with 80% diesel. Similarly, the other mixed biodiesel blends were prepared with 40%, 60%, and 80%, respectively. M100 being the mixture of these three biodiesel blends in equal proportions. All these six biodiesel blends were accomplished via a magnetic stirrer for 30 minutes at 500 rpm to get the homogeneous solution.

3. Experimental Setup

An investigation on a computerized diesel engine assessed the performance and exhaust emissions of various mixed biodiesel blends (MB20, MB40, MB60, MB80 and MB100) compared to MB0. The blends contained 20%, 40%, 60%, 80%, and 100% mixed biodiesel with MB0 (diesel). Additionally, MB100 was mixed with the additive diethyl ether in three proportions, namely MB95E5, MB90E10, and MB85E15, which indicates that mixed biodiesel blends are added with additives in 5, 10 and 15%.

Experiments on a computerized single-cylinder, four-stroke, direct injection diesel engine using mixed biodiesel involved measuring fuel consumption with an optical sensor and airflow rate with a differential pressure transducer. An eddy current dynamometer varied the engine load, while an AVL-444 digas analyzer and AVL 437 Smoke meter measured emissions and smoke opacity. Thermocouples recorded temperatures, with load changes from no load to maximum in 0.5 kW increments.

Kirloskar made TV 1 model Di diesel engine is taken for experimentation. It runs at a persistent speed of 1500 rpm and produces maximum power output of 5.2 kW. Eddy current dynamometer which is on water cooling is adopted to load the engine. The engine is loaded by the rotation of knob provided in the loading unit which can rotate in the load indicator dial.

The schematics of experimental setup are depicted in Fig 1. The experimental unit consists of engine, 15 liters fuel storage tank along with fuel measuring unit, air box to avoid fluctuation in air supply measurement to engine, Eddy current dynamometer and other standard fittings. Transmitters for fuel adopting Piezo sensor of 5000 psi. The data acquisition process is made by adopting "Engine Soft- LV" software version. The detailed engine specifications are tabulated below in Table.1.

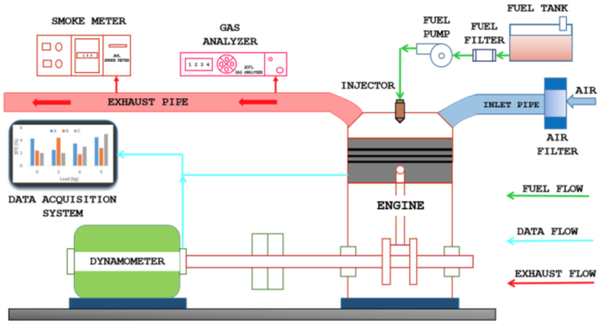

Fig. 3 Experimental Setup [19]

Table.1 Engine Specifications

Model and type	KirloskarTv1, four stroke, CI engine
Injection of fuel	Direct injection
Number of cylinders	Single cylinder
Cooling type	Water cooling
Rated speed	1500rpm
Rated out put	5.2kw at 1500rpm
Nozzle pressure	220bar
Default combustion chamber	Hemispherical chamber
Fuel injection timing	23,CA BTDC
Bore	87.5mm
Stroke	110mm
Swept volume	661cc
Fuel	Diesel
Orifice diameter	20mm
Arm length	185mm

4. Results and Discussions

4.1 Mixed Biodiesel Blends

The experiments were conducted with various biodiesel blends, including pure diesel. The readings were noted, and the performance and emission characteristics were determined.

Brake Thermal Efficiency

The Fig. 4 depicts how Brake Thermal Efficiency (BTE) varies with Brake Power (BP) for different fuel blends, including Diesel, MB20, MB40, MB60, MB80, and MB100. The trend shows that as brake power increases, BTE also rises for all fuel types, which is expected due to improved combustion efficiency at higher loads. Among the tested fuels, diesel consistently achieves the highest BTE across all power levels, while biodiesel blends generally show a decline in efficiency. This drop in BTE with higher biodiesel concentration is mainly due to its lower calorific value and higher viscosity, which result in poor fuel atomization and incomplete combustion. However, moderate biodiesel blends such as MB20 perform better than the higher blends (MB40, MB60, MB80, MB100), indicating an optimal balance between fuel properties and combustion efficiency. Brake Thermal Efficiency increases with load for all biodiesel blends, with MB20 showing the highest BTE (27.8%) and MB100 the lowest (26.13%) at full load.

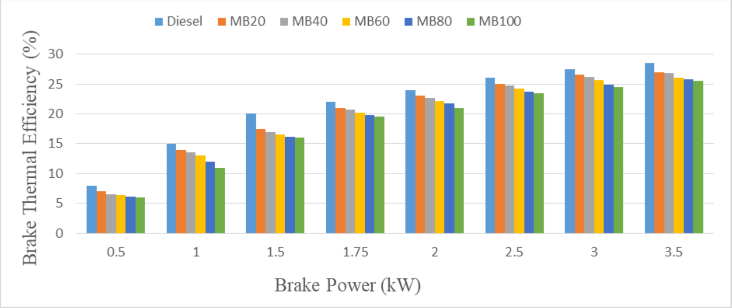

Figure 4. Variation of BTE with Brake Power

Brake Specific Fuel Consumption

Figure 5 shows the variation of Brake Specific Fuel Consumption (BFSC) with Break Power (BP). BSFC for mixed biodiesel is higher than diesel, decreasing with increased brake power across all blends. At maximum load, BSFC is 0.307 and 0.327 kg/kWh for blends MB20 and MB100, respectively. Its BSFC values are 4.07% and 10.85% higher when compared to diesel's 0.295 kg/kWh due to higher viscosity, specific gravity, and lower heating value.

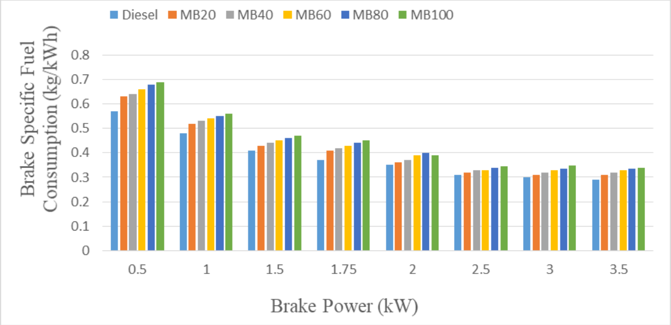

Figure 5 Variation of BFSC with Break Power

Exhaust Gas Temperature

In Figure 6, Exhaust Gas Temperature (EGT) increases with load for biodiesel blends, with MB100 showing the highest EGT (453°C) and a 16.75% deviation compared to diesel (388°C) at maximum load. This rise is due to reduced friction power under full load conditions. The

MB80 biodiesel with the highest EST value is 495°C at the full load conditions, which is a 27.58% increase when compared to diesel.

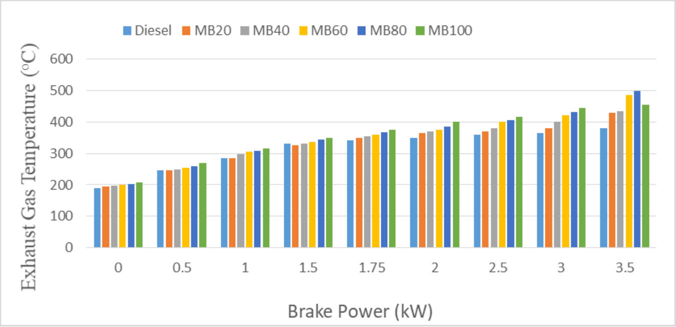

Figure 6 Variation of EGT with Brake Power

Carbon Monoxide (CO)

The Fig. 7 shows the variation of CO with brake power. The decrease in CO emissions with increasing load across different biodiesel blends compared to diesel is attributed to improved combustion efficiency and higher oxidation rates in the engine cylinder, resulting from higher temperatures.

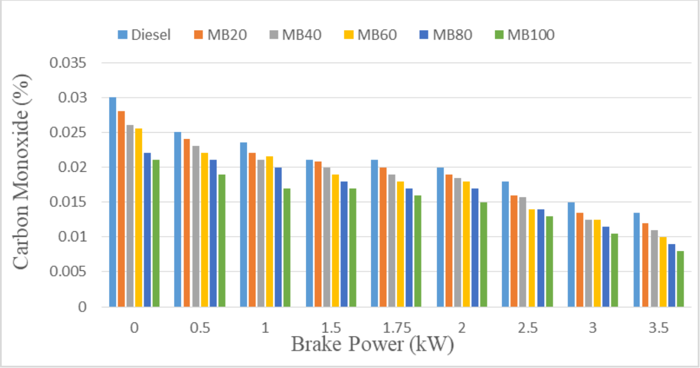

Figure 7 Variation of CO with Brake Power

Hydrocarbon (HC)

From Fig. 8, it can be seen that HC emissions decrease with increasing load for mixed biodiesel blends compared to diesel. This is attributed to their higher oxygen content promoting more complete combustion, resulting in emissions ranging from 9 ppm to 12 ppm across different blends.

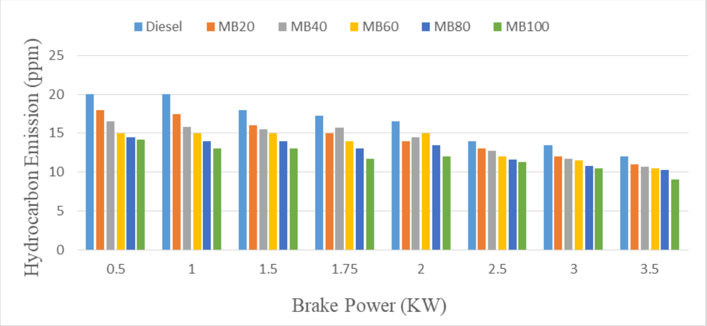

Figure 8 Variation of HC with Brake Power

Oxides of Nitrogen (NO_x)

Fig. 9 shows the variation of Nox with Brake Power. NO_x emissions for mixed biodiesel blends are higher than diesel, with variations ranging from 7.64% to 16%. This is attributed to higher adiabatic flame temperatures and increased oxygen concentrations in the fuel spray envelope during combustion.

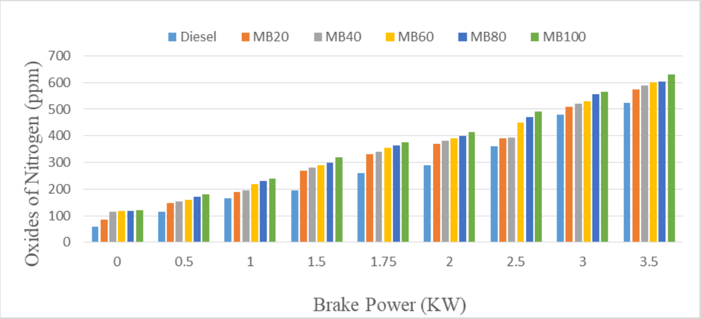

Figure 9 Variation of NO_X with Brake Power

Smoke opacity/Smoke Emission

Smoke opacity for mixed biodiesel blends is consistently lower than diesel, with reductions ranging from 4.88% to 9.75% at full load as shown in Fig. 10. This improvement is attributed to the presence of oxygen in the biodiesel blends, enhancing combustion efficiency under maximum load conditions.

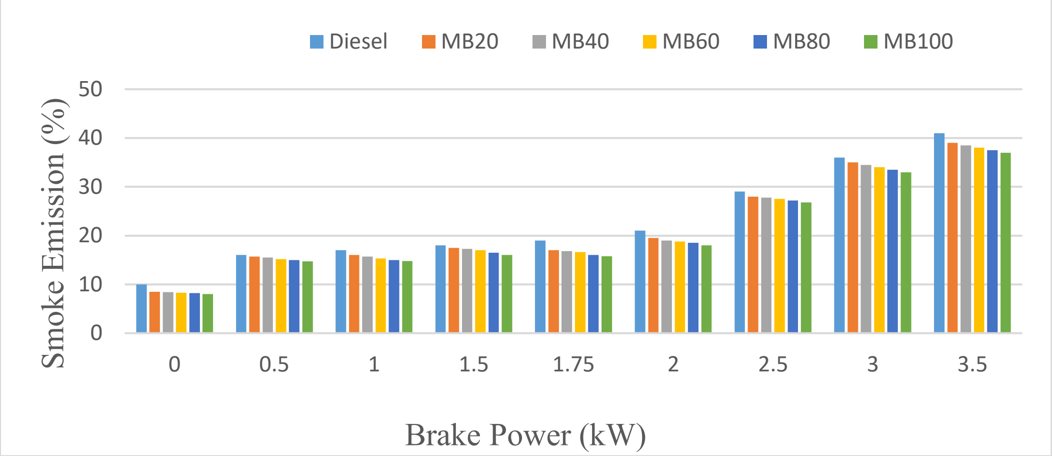

Figure 10 Variation of Smoke Emission with Brake Power

From the results, it can be seen that MB20 provide better results compared to other biodiesel blends. Further, this MB20 is considered for further analysis with the additive. The additive diethyl ether is mixed with the biodiesel in three proportions and named MB95E5, MB90E10, and MB85E15. Further, MB20 is considered MB100 when the additive diethyl ether is added.

4.2 Mixed biodiesel blends with diethyl ether additive

The Fig. 11 depicts how Brake Thermal Efficiency (BTE) changes with Brake Power (BP) for various fuel blends. MB20, a biodiesel blend, serves as the base fuel, while the other blends include different amounts of diethyl ether (DEE) as an additive. The tested fuel combinations consist of MB100 (pure biodiesel), MB95E5 (95% biodiesel + 5% DEE), MB90E10 (90% biodiesel + 10% DEE), and MB85E15 (85% biodiesel + 15% DEE), with Diesel included as a benchmark.

A common trend observed is that BTE increases as brake power rises, which is expected due to improved combustion efficiency at higher loads. However, the efficiency differs notably among the blends. Diesel and MB85E15 (biodiesel with 15% DEE) demonstrate the highest BTE, highlighting the positive impact of DEE on fuel performance.

BTE for mixed biodiesel is lower than diesel for all the blends used in the current study but increases with load and further improves with diethyl ether (DEE) additives. At full load, 5%, 10%, and 15% DEE additions increase BTE by 0.87%, 1.37%, and 1.87%, respectively (as shown in Fig. 11), due to reduced viscosity and better fuel atomization.

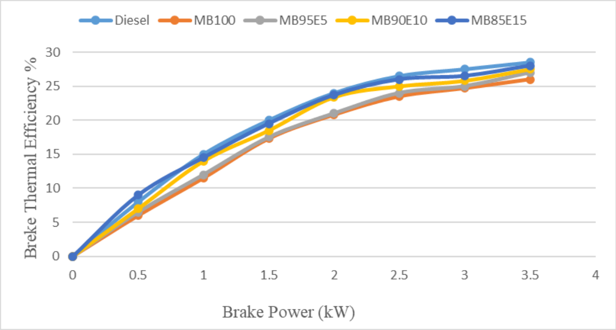

Figure 11 BTE vs Brake Power

Fig. 12 shows the BSFC vs Brake Power with the DEE additive blended in biodiesel. BSFC decreases with increasing load and is higher for mixed biodiesel than diesel. Adding 5%, 10%, and 15% DEE to mixed biodiesel reduces BSFC by 2.04%, 3.57%, and 5.10%, respectively, due to increased heating value and reduced viscosity.

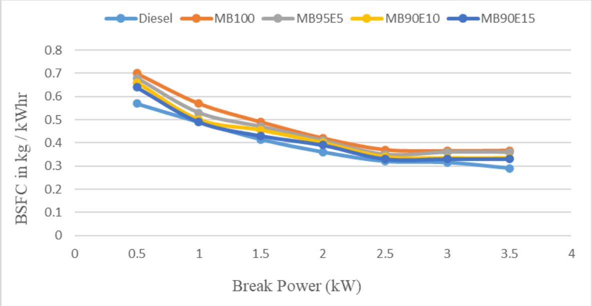

Figure 12 BSFC vs Break Power

The exhaust gas temperature (EGT) increases with applied load, but decreases with the addition of DEE to mixed biodiesel (as shown in Fig. 13). Adding 5%, 10%, and 15% DEE reduces EGT by 8°C, 23°C, and 33°C respectively, compared to 100% biodiesel, due to improved combustion and increased heating value.

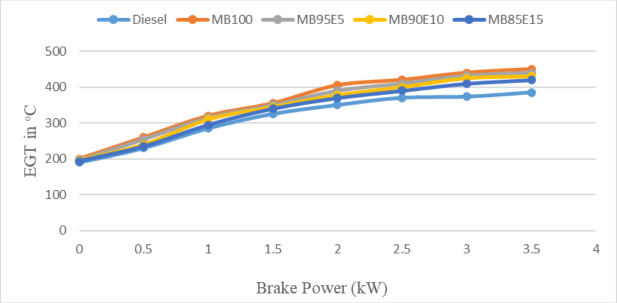

Figure 13 EGT vs Brake Power

CO emissions decrease with increased load and are lower for MB100 than diesel at full load as shown in Fig. 14. Adding DEE to mixed biodiesel further reduces CO emissions by 22.22% for

MB95E5, 33.33% for MB90E10, and 44.44% for MB85E15 at full load due to higher oxygen content and more complete combustion.

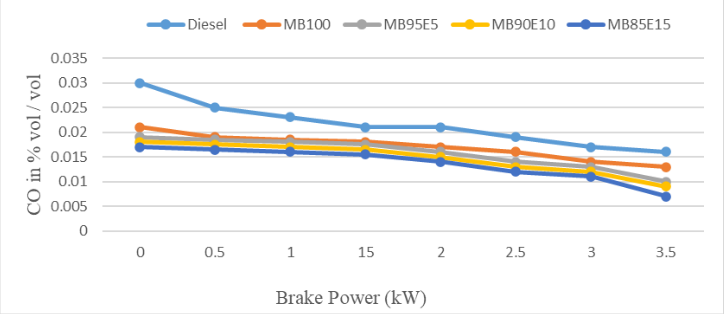

Figure 14 CO vs Brake Power

Adding DEE to mixed biodiesel increases CO_2 emissions by 6.17%, 25.93%, and 29.63% for 5%, 10%, and 15% DEE, respectively. This indicates higher CO_2 emissions with increased DEE content than neat mixed biodiesel as shown in Fig. 15.

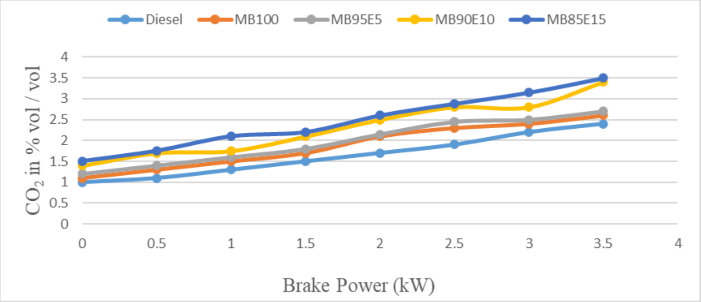

Figure 15 Break Power vs CO_2

HC emissions increase with load, but are lower with MB95E5, MB90E10, and MB85E15 compared to neat mixed biodiesel (shown in Fig. 16), showing reductions of 9%, 19%, and 22% respectively at full load. This decrease is due to heat absorption within the cylinder, reducing temperature and HC emissions.

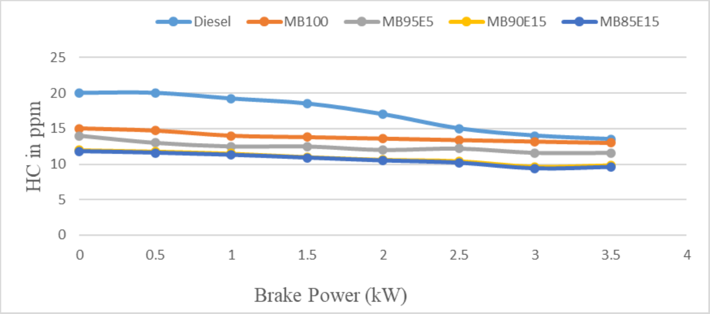

Figure 16 HC vs Brake Power

NOx emissions increase with load, but adding DEE to mixed biodiesel decreases them (shown in Fig. 17). MB85E15 reduces NOx emissions at full load by 3.69%, 6.9%, and 7.54% compared to MB100 due to better combustion and reduced EGT in the cylinder.

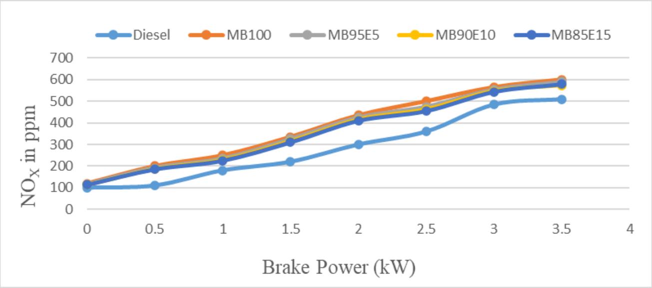

Figure 17 NO$_X$ vs Brake Power

Smoke emissions decrease with DEE blends in mixed biodiesel, with reductions of 8.11% for MB95E5, 13.51% for MB90E10, and 16.22% for MB85E15 compared to neat mixed biodiesel (shown in Fig. 18). At full load, neat mixed biodiesel emits less smoke than diesel, and adding DEE further reduces emissions due to oxygen presence and lean fuel mixture.

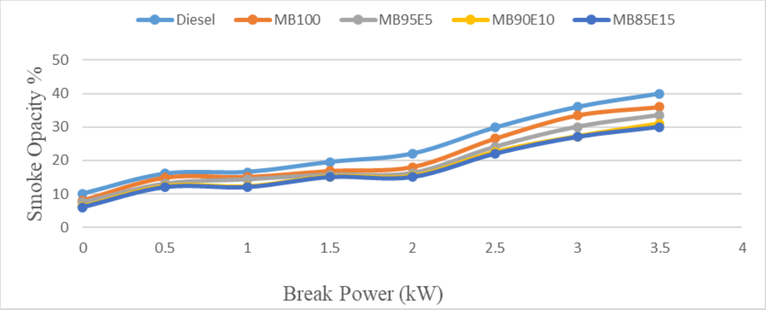

Figure 18 Smoke Opacity vs Break Power

5. Conclusions

Experiments conducted with different blends of mixed biodiesel in a CI engine under various loads revealed several performance and emission characteristics.

- The mixed biodiesel blend MB20 exhibited a higher Brake Specific Fuel Consumption (BSFC) by 5.08% and a lower Brake Thermal Efficiency (BTE) by 3.13% compared to diesel at maximum load.
- The Exhaust Gas Temperature (EGT) of mixed biodiesel blends was comparable to diesel, with MB20 and MB100 showing an increase of 8.24% and 16.75%, respectively.
- Emission analysis indicated that the presence of hydrocarbons (HC) and carbon monoxide (CO) in the exhaust gas of MB20 was lower than diesel by 8.33% and 7.69%, respectively. At peak load, MB100 emitted 19.58% more carbon dioxide (CO_2) than diesel, while MB20 emitted 11.25% less CO_2 than MB100.

- Nitrogen oxide (NOx) emissions were higher for MB20 by 7.64% and for MB100 by 16% compared to diesel. Furthermore, the smoke emissions decreased by 9.75% at full load compared to diesel emissions.

Experiments directed on a DI diesel engine using mixed biodiesel with diethyl ether as an additive, added at concentrations of 5%, 10%, and 15%. The addition of diethyl ether revealed significant performance and emission changes at 15% additive concentration under maximum load.

- The BTE increased by 1.87%, while the BSFC decreased by 5.10%.
- The Exhaust Gas Temperature (EGT) showed a substantial rise of 16.91%.
- Emission measurements indicated considerable reductions in CO by 44.44%, HC by 22%, and smoke emissions by 16.22%. However, carbon dioxide (CO2) emissions increased from 6.17% to 29.63%, and nitrogen oxide (NOx) emissions rose from 4.33% to 17.17%.

The experiments show that mixed biodiesel performance and emissions are comparable to diesel. Therefore, biodiesel from Raphanus sativus, Jatropha, and Balanitis aegyptiaca seeds is a viable diesel alternative. The research finds that biodiesel blends with diethyl ether are a potential substitute fuel with better engine performance and lower toxic emissions.

References:

1. S. N. Shah, O. K. Iha, F. C. S. C. Alves, B. K. Sharma, S. Z. Erhan, and P. A. Z. Suarez, "Potential application of turnip oil (Raphanus sativus L.) for biodiesel production: Physical–chemical properties of neat oil, biofuels and their blends with ultra-low sulphur diesel (ULSD)," *Bioenergy Research*, vol. 6, pp. 841–850, Feb. 2013. doi: 10.1007/s12155-013-9310-y.
2. N. Chammoun, D. P. Geller, and K. C. Das, "Fuel properties, performance testing and economic feasibility of Raphanus sativus (oilseed radish) biodiesel," *Industrial Crops and Products*, vol. 45, pp. 155–159, 2013. doi: 10.1016/j.indcrop.2012.11.029.
3. A. Roy, Y. Dabhi, H. Brahmbhatt, and S. K. Chourasia, "Effect of emulsified fuel based on dual blend of Castor-Jatropha biodiesel on CI engine performance and emissions," *Alexandria Engineering Journal*, vol. 60, pp. 1981–1990, Dec. 2020. doi: 10.1016/j.aej.2020.12.003.
4. HS, Anantha Padmanabha, and Dillip Kumar Mohanty. "Enhancement of combustion, performance and emission characteristics of diesel engines fuelled with jatropha-karanja biodiesel using EGM and TGME as additive." Energy 300 (2024): 131523. https://doi.org/10.1016/j.energy.2024.131523.
5. S. Bajpai and L. M. Das, "Experimental investigations of an IC engine operating with alkyl esters of Jatropha, Karanja and Castor seed oil," *Energy Procedia*, vol. 54, pp. 701–717, 2014. doi: 10.1016/j.egypro.2014.07.311.
6. S. Brahma, B. Nath, B. Basumatary, B. Das, P. Saikia, K. Patir, and S. Basumatary, "Biodiesel production from mixed oils: A sustainable approach towards industrial

biofuel production," *Chemical Engineering Journal Advances*, vol. 10, p. 100284, Mar. 2022. doi: 10.1016/j.ceja.2022.100284.

7. M. T. Lamore, D. S. Zeleke, and B. Y. Kassa, "A comparative study on the effect of nano-additives on performance and emission characteristics of CI engine run on castor biodiesel blended fuel," *Energy Conversion and Management: X*, vol. 20, p. 100493, Nov. 2023. doi: 10.1016/j.ecmx.2023.100493.
8. A. F. Fareed, A. S. El-Shafay, M. A. Mujtaba, F. Riaz, and M. S. Gad, "Investigation of waste cooking and castor biodiesel blends effects on diesel engine performance, emissions, and combustion characteristics," *Case Studies in Thermal Engineering*, vol. 60, p. 104721, Jun. 2024. doi: 10.1016/j.csite.2024.104721.
9. Pugazhendhi, Arivalagan, et al. "Enhancing sustainable fuel solutions: Castor oil biodiesel with nanoparticles and ammonia, utilizing as a green substitute for diesel engines." Fuel 368 (2024): 131597. https://doi.org/10.1016/j.fuel.2024.131597
10. Bhupesh Sahu, Ajay Singh Paikra, Dilbag S Mondloe & Himanshu Agrawal 2018, 'Performance and emission characteristics of diesel engine working on Jatropha Methyl Ester and its blends', International Research Journal of Engineering and Technology, vol. 5, pp. 682-688.
11. Abed, KA, Gad, MS, El Morsi, AK, Sayed, MM & Abu Elyazeed, MM 2019, 'Effect of biodiesel fuels on diesel engine emissions', Egyptian Journal of Petroleum vol. 28, pp. 183–188.
12. Deepak Agarwal & Avinash Kumar Agarwal 2007, 'Performance and emissions characteristics of Jatropha oil (preheated and blends) in a direct injection compression ignition engine', Applied Thermal Engineering, vol. 27, pp. 2314-2323.