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SCIENTIFIC PAPER

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COMPARATIVE ANALYSIS OF MORINGA OIL AND RUBBER SEED OIL BIODIESELS IN DIESEL ENGINES

Highlights

- The performance of biodiesel blends (MO20 and RB20) improves as brake power increases.
- Rubber seed and moringa biodiesel power diesel engines effectively.
- MO20 increases NO_x by 20%, but both MO20 and RB20 reduce UBHC emissions.
- Using moringa oil methyl ester blends as a sustainable alternative to reduce pollution.
- The reduction in emissions is an important benefit of biodiesel.

Abstract

Energy resources are diminishing, and environmental problems are becoming more prevalent. In this regard, biodiesel from moringa oil (MO) and rubber seed oil (RSO) promises to be an excellent alternative to diesel fuels, while also requiring far less modification from existing diesel engines. Performance metrics analysis reveals that biodiesel consumes a slightly higher amount of fuel at lower loads because of its relatively lower calorific value. At 4.4 kW, MO methyl ester blend (MO20) achieved a brake thermal efficiency of 30%, outperforming diesel (26%) and RSO methyl ester blend (RB20) achieved a brake thermal efficiency of 28%. MO20 reduced CO emissions by 60% compared to diesel and 55% compared to RB20. Furthermore, MO20 increased NO_x emissions by 10% at higher brake power levels compared to RB20 and 20% for diesel. RB20 and MO20 biodiesel blends exhibit lower HC compared to diesel by 24% and 28% respectively. These reductions in carbon monoxide and hydrocarbon emissions make biodiesel blends, mostly from MO, cleaner and well sustainable compared to conventional diesel, with their environmental and performance benefits for diesel engine applications.

Keywords: Biodiesel, diesel engine, alternative fuel, moringa oil, rubber seed oil, emissions.

INTRODUCTION

Developing alternative energy sources is a primary priority to reduce fossil fuel use. These solutions must meet rising energy needs sustainably. One notable option is biodiesel, made from waste and non-edible oils. It can be combined with diesel fuel and used in diesel engines, especially those that use non-edible oils, as an eco-friendly alternative to mineral diesel. Diesel engines have thus become popular amongst most consumers in the automobile market for their improved fuel efficiency. However, the finite nature of fossil fuel reserves and the deepening crisis of the environment have prompted scientists to expand their gaze to other fuels that could supplant diesel without an attendant diminution of high performance. In this process, biodiesel, whose origin is related to fatty acid triglycerides, has become a potential candidate. In addition, because only minor modifications are required, diesel engines can be converted into clean, sustainable energy sources without compromising the efficiency of the engines.

Another alternative that can be used is rubber seed oil (RSO). It is a recyclable, environmentally friendly alternative fuel. Oil extracted from the seeds of the rubber tree, which is abyproduct of the latex industry, may help to reduce dependence on fossil fuel and support carbon sequestration. But both biodiesel and rubber esters face challenges as alternative fuels. Blending, pyrolysis, and emulsification increase vegetable oil viscosity. Research suggests that one method to improve. Transesterification gives oils and fats fuel characteristics [1,2]. One species that is frequently grown is *M. oleifera*, which is evergreen, grows quickly, and has deciduous leaves [3]. Due to its high

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viscosity, pure vegetable oil makes it difficult to atomize gasoline and causes the fuel spray to penetrate deeper into the material. Problems with engine deposits and lubricating oil thickening are partially caused by this greater penetration [4].

Biodiesel is a viable and environmentally sustainable alternative to traditional fossil fuels, especially petroleum-derived diesel [5-7]. Sustainable transition to renewable sources is a good way to mitigate climate change and ensure future generations can satisfy their energy demands [8-10].

Ozsezen and Canakci [10] revealed that waste palm oil methyl esters or canola oil methyl esters instead of diesel fuel decreased the brake power (BP) by 4-5% and boosted the brake specific fuel consumption (BSFC) by 9-10%. Methyl esters reduced CO by 59-67%, hydrocarbons (HC) by 17-26%, CO_2 by 5-8%, and smoke opacity by 56-63%. However, they increased NO_x emissions by 11-22% compared to diesel fuel across the speed range. Based on experiments, RSOMEs are a viable compression ignition engine fuel.

RSO with high FFA was successfully converted to biodiesel using a two-step transesterification process, yielding fuel with properties close to diesel [11]. Since exhaust emissions decreased, biodiesel's specific fuel consumption increased by less than 11.4%, which may be acceptable. Researchers found that biodiesel, alone or in blends, can power compression ignition outboard engines, providing an alternative to diesel [12]. It is readily accessible and can meet the escalating global energy demands [13-15]. Rajan and Pradeepraj [13] investigated engine performance with 1-hexanol fumigation utilizing Moringa biodiesel-diesel blend (MOBD). Compression ignition (CI) engine carburetoring of *n*-hexanol into the intake manifold was tested. It was shown that 10% *n*- hexanol fumigation enhanced MOBD25 brake thermal efficiency (BTE) by 1.08% compared to other diesel and other fumigation ratios. MOBD25 fumigated with 30% *n*- hexanol reduced NO_x and smoke by 36% and 38%. The result shows that 30% *n*-hexanol fumigation in the MOBD25 blend greatly decreased NO_x emissions with a BTE penalty. Rajaraman *et al.* [14] observed *M. oleifera* biodiesel (B20 and B100) blending and engine performance and exhaust emissions utilizing a direct injection CI engine at full load. The trials showed that *M. oleifera* blended fuel had worse thermal efficiency than standard diesel fuel due to its high viscosity, density, and reduced calorific value. Compared to diesel fuel, *M. oleifera* mixed fuel produced less PM, CO, HC, and NO_x [15]. The biodiesel production process involves an acid-catalyzed pretreatment followed by alkaline-catalyzed transesterification. The key properties of RSOMEs are compared with those of other esters and diesel fuel.

Ramalingam and Mahalakshmi [16] investigated biodiesel-diesel-1-hexanol (B-D-H) and *M. oleifera* biodiesel-diesel-ethanol (B-D-E) mixes using a compression ignition engine. Test results indicate B90-D5-H5 had the lowest BSFC and the greatest BTE, 0.375 kg kW^{-1} h^{-1} and 28.8%. His greatest NO_x emission was 1090 ppm in B80-D5-E15. B100 had the lowest NO_x of (846 ppm), maximum HC emissions (34 ppm) at 100% load, and lowest smoke opacity (34%). Unfortunately, biodiesel-diesel-alcohol mixtures enhanced engine performance but reduced emissions like normal diesel. Diesel usage decreases with biodiesel-diesel-alcohol mixtures. Thus, ethanol and 1-hexanol are the best blending diesel for fuel quality, performance, and emissions.

Rashed *et al.* [17] explore the performance and emissions of moringa biodiesel-fueled diesel engines compared to palm, jatropha, and diesel fuel. This article evaluated only 20% of each biodiesel in the diesel engine, even though open literature suggests using up to 20% without modification. Blended fuel reduces average CO and HC emissions, apart from NO_x, compared to diesel fuel. *M. oleifera* is commonly referred to as "behen oil" or "ben oil" due to its high content of behenic acid (docosanoic acid). These characteristics make *M. oleifera* oil suitable for biodiesel production [18]. There are numerous biodiesel feedstocks, including edible and non-edible oils (*Ceiba pentandra*, palm, *Jatropha curcas*, *Calophyllum inophyllum*, waste food oils) and animal fats (tallow and lard) [19-24]. Energy is essential for our daily lives, driving human development and fostering economic growth and productivity. Salaheldeen *et al.* [19] evaluated the performance, emissions, and combustion of diesel and RSO methyl esters (RSOMEs) blends in a direct injection diesel engine at 19°, 23°, and 27° 19°, 23°, and 27° bTDC. At 19° bTDC, RB20 had lower energy content and viscosity than diesel and moringa oil (MO), resulting in improved BTE and reduced specific fuel consumption. Diesel and RB20 had equivalent fuel usage and lower CO emissions. Advance injection timing boosted NO_x emissions, while retarding it improved fuel economy, HC and CO emissions, and RB20 thermal efficiency. Taguchi found a multi-response signal-to-noise ratio of 23 optimum. Biodiesel spray properties are theoretically analyzed in the study. Saravanan *et al.* [20] found that the crude rice bran oil methyl esters (CRBMEs) had a lower delay period and maximum pressure rise than diesel. The CRBME blend also released heat earlier than diesel, but the difference was smaller. According to Sivalakshmi and Balusamy [21], neem oil-alcohol blends improve the BTE. These blends reduce smoke, CO, and HC at higher loads. When compared to pure neem oil, the mixes eliminated NO_x emissions minimally, except for the ethanol blend.

Soudagar *et al.* [22] reported trans-esterification of *M. oleifera* oil to make biodiesel under working circumstances. B10 and B20 biodiesels are compared to high-speed diesel in a compression ignition engine for performance and emissions. Engine speed ranged from 1000 to 2400 rpm at full load. All performance and exhaust pollutant results were analyzed. MO10 produced 7.44%, 7.51%, and 7.7% reductions in the BP, BSFC, and CO_2. Smoke opacity and HC decreased 24% and 10.27% for MO10. MO10 has 2.5% and 9% higher CO and NO_x emissions than diesel. Tamilselvan *et al.* [23] published an extensive analysis of diesel engines that run on biodiesel, including their performance, combustion, and emission parameters. The current studies show that biofuels are the greatest way to enhance gasoline quality. Sustainable, oxygenate-free, sulfur-free, and biodegradable biofuels are amazing. Biofuels are also a great option considering efficiency, as they could run on the existing diesel engines and do not require any adjustment whatsoever. Scientists have taken extreme and considerable tests on the diesel engine to prove their supremacy over standard fuels based on indicators of emissions and performance. In this article, pure biodiesel in the engine and the combustion of biodiesel with fuel will be thoroughly examined. This paper is a good study wherein biodiesel CO_2, CO, HC, and NO_x are utilized in a diesel engine. Venkanna and Reddy [24] demonstrated that warmed honne oil improves BTE and exhaust gas temperature (EGT). Preheated honne oil emits more NO_x than unheated, although emissions of SO, CO, and HC are lower.

The global use of biodiesel is steadily increasing as countries seek sustainable alternatives to fossil fuels and aim to reduce environmental pollution. Biodiesel derived from renewable sources not only lowers greenhouse gas emissions but also enhances energy security [25]. Among emerging feedstocks, RSO and MO show strong potential for widespread adoption, especially in regions with rich agricultural resources. This study investigates the performance and emission characteristics of RB20 and MO20 blends, emphasizing their suitability for large-scale application as clean, efficient substitutes for conventional diesel [26,27]. While studies have highlighted the potential of biodiesel blends MO20 and RB20 in improving engine performance and reducing emissions, there is limited research comparing these blends in terms of long-term performance, engine durability, and optimal blend ratios. Further studies are needed to explore the feasibility of these biodiesels as sustainable alternatives to diesel under varying operational conditions.

The twin challenges of the world are fossil fuel depletion and environmental pollution. Increasing costs and depleting hydrocarbon reserves require alternative fuels to fulfill growing energy needs and reduce environmental damage. The present study examined MO methyl esters (MOMEs) and RSOMEs blends (MO20 and RB20) as biodiesel alternatives. This study highlights the potential of MO20 and RB20 biodiesel blends as sustainable alternatives to conventional diesel. The research demonstrates that these biodiesel blends improve engine performance as the brake power (BP) increases. Notably, MOME blends reduce NO_x emissions by 20% compared to diesel, offering a significant environmental benefit. These findings underscore the role of biodiesel in reducing emissions, making it a promising solution for cleaner, more efficient fuel use in diesel engines.

MATERIALS AND METHODS

Fuel Preparation

MO was extracted from the seeds of the *M. oleifera* plant through cold-pressing. The extracted oil underwent a two-step transesterification process. First, an acid-catalyzed pretreatment was conducted using sulfuric acid to reduce the high FFA content below 1%. Subsequently, a base-catalyzed transesterification was performed using methanol (molar ratio of 6:1) and sodium hydroxide (NaOH) as a catalyst at 60 °C for 1.5 hours. After the reaction, the mixture was allowed to settle in a separating funnel, leading to two distinct layers: biodiesel (upper layer) and glycerol (lower layer). The biodiesel layer was washed with warm distilled water to remove residual catalyst and methanol and then dried at 110 °C to eliminate moisture, yielding MOME.

RSO was obtained from rubber tree seeds (*Hevea brasiliensis*) through mechanical expeller pressing. Due to the higher free fatty acid (FFA) content in raw RSO, a similar two-step esterification method was used. Initially, the oil was treated with sulfuric acid and methanol to reduce the FFA level. The second stage involved base-catalyzed transesterification using methanol (molar ratio of 6:1) and potassium hydroxide (KOH) as a catalyst, maintaining a reaction temperature of 60 °C for 2 hours. The resulting mixture was separated into biodiesel and glycerol layers. The biodiesel was washed thoroughly with warm water and dried to achieve a pure RSO methyl ester. After confirming that both biodiesel samples met ASTM D6751 fuel standards, they were blended with mineral diesel at a ratio of 20% biodiesel to 80% diesel by volume to prepare MO20 and RB20 blends. *M. oleifera* is known for its high oil content and ability to reduce emissions, particularly NO_x, while RSO is widely available as a by-product of the rubber industry, making it a cost-effective and sustainable option. Both oils have shown promising results in previous studies for their fuel properties and environmental benefits, which motivated their inclusion in this research. The goal was to compare these biodiesel blends for their potential to improve engine performance and reduce harmful emissions when used in existing diesel engines. These blends were used for engine testing without any modification to the diesel engine. Table 1 shows the tested properties of Diesel, MO20, and RB20.

Experimental technique

The experimental investigation was carried out using a single-cylinder, four-stroke, water-cooled, naturally aspirated, direct injection (DI) diesel engine rated at 4.4 kW at 1500 rpm, as shown in Figure 1. The engine was coupled to an eddy current dynamometer equipped with a digital torque indicator and load control mechanism for precise loading conditions. A fuel measurement system consisting of a burette and a stopwatch was used to measure the fuel consumption by recording the time taken for a fixed volume of fuel. An AVL 444 Digas gas analyzer was used to measure exhaust gas emissions, including CO, HC, and NO_x. The specification of the emission measurement instrument is represented in Table 2. For combustion analysis, an AVL indimeter system, incorporating an in-cylinder pressure transducer (AVL GH12D), crank angle encoder, and data acquisition system, was employed to monitor the cylinder pressure variation, rate of heat release, and ignition delay. The cooling water flow rate was maintained constant to ensure consistent operating temperatures. Prior to each test, the engine was warmed up for 20 minutes to reach steady-state conditions. Fuel tanks were cleaned before switching fuels to prevent

Table 1. Properties of pure oils, pure biodiesels, blends, and diesel.

Property	MO	RSO	MOME	RSOME	MO20 blend	RB20 blend	Diesel
Density at 20 °C, (kg/m³)	910	920	870	880	842	882	840
Calorific value (kJ/kg)	39.000	38.500	42.000	41.800	42.460	41.522	43.000
Specific gravity	0.91	0.92	0.87	0.88	0.90	0.91	0.84
Viscosity (cSt)	35.6	32.4	5.5	5.8	3.6	5.2	2.5-3.2
Flash point (°C)	220	210	170	160	84	125	65
Fire point (°C)	240	230	190	180	92	152	78
Cetane number	47	45	52	50	64	43	45-55

Table 2. Specification of the emission measurement instruments.

Instrument name	Measured emissions	Model	Manufacturer	Measurement range	Accuracy
AVL DiGas 444 Analyzer	CO, HC, NO_x	DiGas 444	AVL, Austria	CO: 0-10%, HC: 0-20,000 ppm, NO_x: 0-5000 ppm	±1% of full-scale reading

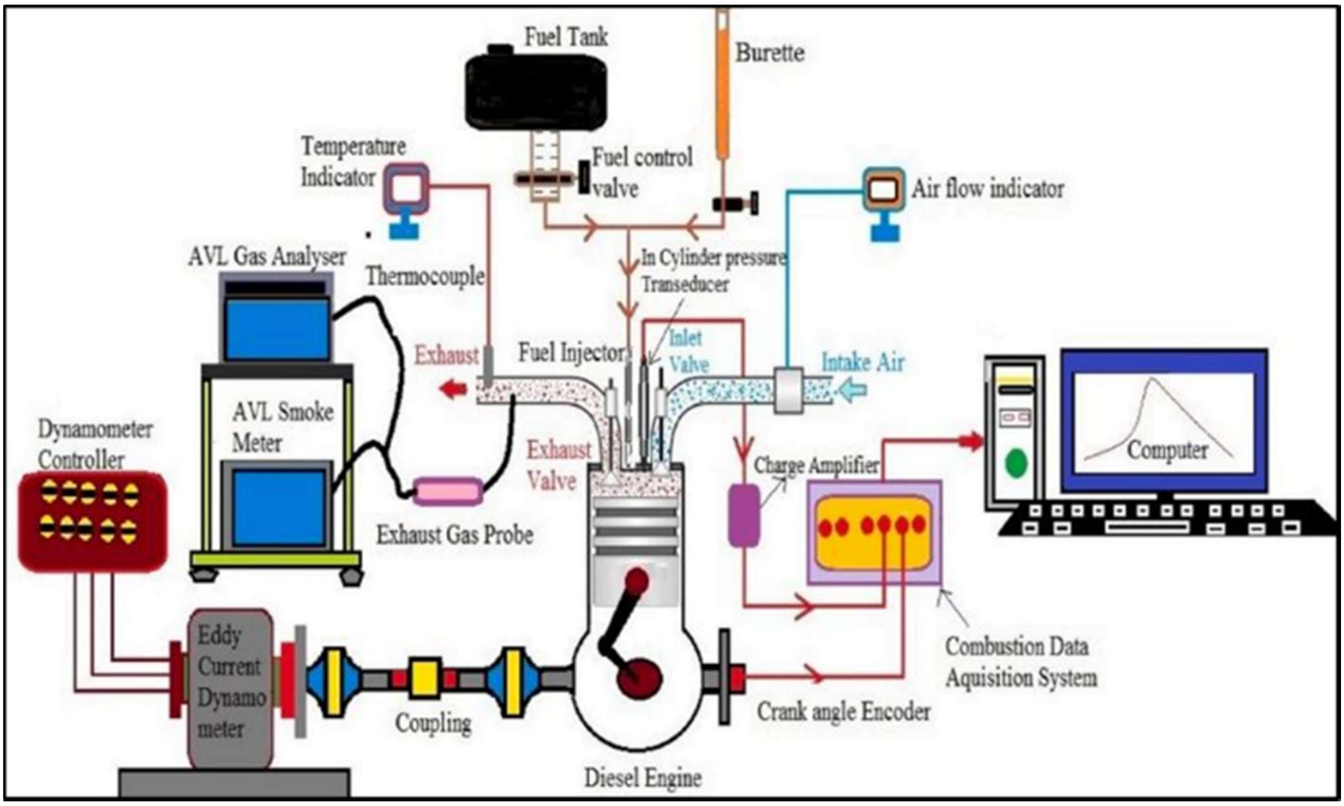

Figure 1. Experimental setup.

contamination. The baseline readings were first recorded using neat diesel fuel, followed by testing with MO20 and RB20 blends under identical loading conditions. All experiments were conducted at a constant engine speed of 1500 rpm, varying the load incrementally from no load to full load in steps, and measurements were repeated three times to ensure repeatability. The ambient temperature and barometric pressure were also recorded during testing to account for environmental influences. Uncertainty analysis was performed for the experimental measurements and found to be within acceptable limits: ±2.1% for the BTE, ±2.0% for the BP, and ±2.11% for the BSFC. Emission measurements had uncertainty levels of ±0.1% for CO, ±5 ppm for HC, and ±0.11% for NO_x. A computer processed the data, including parameters like power output, torque, and fuel consumption, while an AVL combustion analyser measured the rate of heat release and emissions (including NO_x, CO, and HC [12].

Test Methodology

The engine's maximum torque was initially estimated, and it was then started under no-load conditions using a hand crank with the decompression lever activated. After initiating the engine, it was allowed to run under no-load conditions for several minutes to ensure that the speed stabilized at its rated value. The engine was then operated at a constant speed while monitoring fuel consumption, utilizing a time indicator calibrated for a 10-cc fuel quantity. An eddy current dynamometer was employed to conduct experiments under variable load conditions. Testing was performed using biodiesel, and the results were meticulously recorded. This procedure was replicated under identical operating conditions for all fuel blends tested, including diesel and biodiesel blends of MO20 and RB20. The exhaust gas temperature was measured under the same operating conditions for each blend in the range of 350-400 °C for low load to full load. To ensure the experiment's accuracy, uncertainty analysis is necessary. At 0.7%, 0.18 s, and 2.01 of fuel, time, and braking power testing were accurate. A digital dynamometer (accuracy ±0.1%) was employed for the BP measurement, and a calibrated gas analyzer (accuracy ±2%) was used for emission parameters such as CO, HC, and NO_x. All instruments were calibrated before testing according to the manufacturer's guidelines. This systematic approach highlights the relevance and precision of the measurement tools and strengthens the credibility of the reported data. The BSFC of +2.11, the BP of +2.01, and the BTE of +2.10 uncertainties were computed using root-sum-square measurement. The uncertainty on measured exhaust emission values was estimated using the measuring range and resolution of the instrument for each emission component, and the values were CO = +0.1%, HC = +0.005%, and NO_x = +0.00011%, respectively. MOMEs and RSOMEs were selected according to Rajaraman *et al.* [14].

RESULTS AND DISCUSSION

The experimental results for engine performance and emissions characteristics using diesel, MO20, and RB20 fuel blends are presented and discussed in this section. Key performance indicators such as the BSFC and BTE are evaluated, along with critical emission parameters including CO, HC, and NO_x. The discussion highlights the influence of biodiesel blends on engine behavior under varying load conditions, comparing their performance against conventional diesel fuel. RB20 and MO20 biodiesel blends suggest a strong potential for real-world applications. These blends can be used in existing diesel engines with minimal modifications, promoting a smoother transition toward renewable fuels. However, practical challenges must be considered before large-scale adoption. Issues such as fuel stability over long storage periods, the slightly higher viscosity of biodiesel blends, cold flow properties in colder climates, and the current limitations in large-scale production and supply infrastructure may affect widespread use. The findings reveal that biodiesel blends, particularly MO20, can enhance engine efficiency and significantly reduce pollutant emissions, offering a promising alternative to fossil diesel in compression ignition engines.

Performance Characteristics

Consideration of engine performance, as measured by metrics like the BSFC and BTE, is crucial for determining fuel economy. BSFC as a function of the BP is illustrated in Figure 2 for diesel, biodiesel blends (RB20 and MO20), and other fuels. An integral part of the BSFC is the fuel characteristics, including density, viscosity, and heating value.

Figure 2 clearly shows that for all three fuels, the BSFC generally reduces as the BP increases. But the rate at which BSFC declines differs depending on the fuel. When the BP increases, diesel fuel shows the largest reduction in BSFC, whereas RSO and MO show noticeably slower rates of improvement. More specifically, over the whole BP range, MO exhibits a somewhat greater BSFC than diesel. This implies that there may be a slight decrease in fuel efficiency when using moringa biodiesel instead of diesel. One of the most notable findings is how RSO performs. At a low BP, RSO has a somewhat higher BSFC than diesel, but at higher BP levels, it converges with diesel and even exceeds it. For instance, at 1 kW of BP, the BSFC for diesel is approximately 160 g/kWh, while it is higher for RSO(180 g/kWh) and MO (190 g/kWh). However, at 4.4 kW, the BSFC for RSO and diesel converges around 100 g/kWh, suggesting improved fuel efficiency for RSO at higher power levels. BSFC was higher for biodiesel blends (RB20 and MO20) because of higher densities and viscosities are higher and energy densities are lower than diesel fuel. One major reason why fuel atomization is slower in MO20 and RB20 blends is because of their higher viscosity, which in turn leads to poor air-fuel mixing. Soudagar *et al.* [22] reported similar outcomes.

Diesel and biodiesel mixes (RB20 and MO20) are illustrated in Figure 3 along with the relationship between braking power and the BTE. The BTE tends to rise in conjunction with the BP for all three fuels, as seen in Figure 3. This suggests a positive correlation between power production and the efficiency of transferring fuel energy into mechanical work. The fuel economy that increases with increasing BP is highest for diesel, and the rates of improvement are noticeably lower for biodiesel blends (RB20 and MO20). More specifically, RSOME blends show a somewhat poorer BTE over the whole BP range as compared to diesel. It implies that a tiny amount of biodiesel added may cause a slight decrease in fuel efficiency. The performance of MO is possibly the most remarkable finding. At a low BP, MO's BTE is marginally lower than diesel's, but as the BP increases, it converges with diesel and even outperforms it. For all fuels, including diesel and biodiesel mixes (RB20 and MO20), the BTE increases as braking power increases. For instance, at 2 kW, diesel exhibits a BTE of 25%, while MO is slightly lower, at 23%. As the BP reaches 4 kW, MO surpasses diesel, achieving 30% efficiency compared to diesel’s 28%. A decrease in the BTE is a negative effect, related to energy content and fuel consumption when the fuel is changed [22].

Emission Characteristics

Figure 4 shows the correlation between CO emissions and the BP for three distinct fuel types: diesel, biodiesel blends (RB20 and MO20). Figure 4 shows the CO emissions for all diesel, biodiesel blends (RB20 and MO20). CO emissions of all three fuels generally increase as the BP increases. The rate of rise, however, differs greatly throughout the fuels. When the BP increases, diesel fuel shows the highest increase in CO emissions, while biodiesel blends (RB20 and MO20) show noticeably lower emissions. At maximum BP levels, RB20 exhibits a significant decrease in CO emissions relative to diesel. This suggests that adding a small quantity of biodiesel to diesel fuel can significantly reduce emissions. The way that MO20

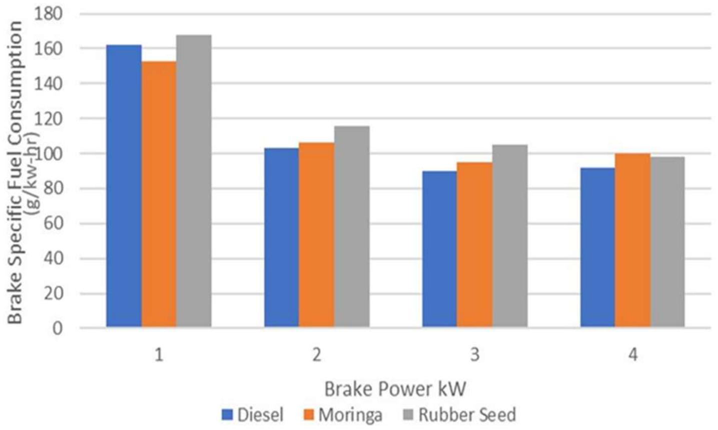

Figure 2. Relationship between the BP with the BSFC for diesel and biodiesel blends (RB20 and MO20).

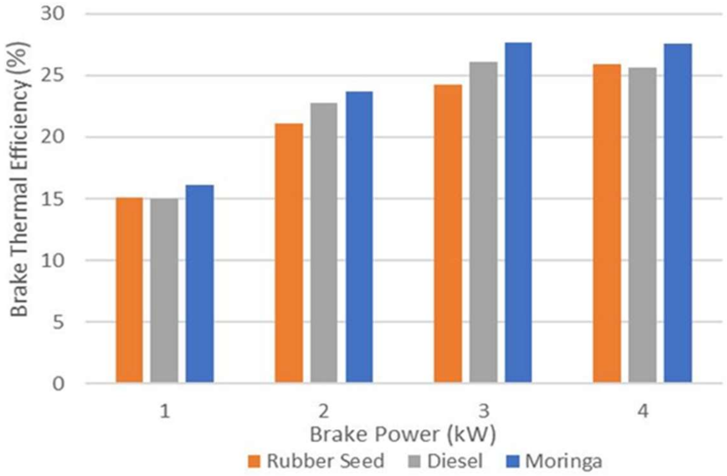

Figure 3. Relationship between the BTE with the BP for diesel and biodiesel blends (RB20 and MO20)

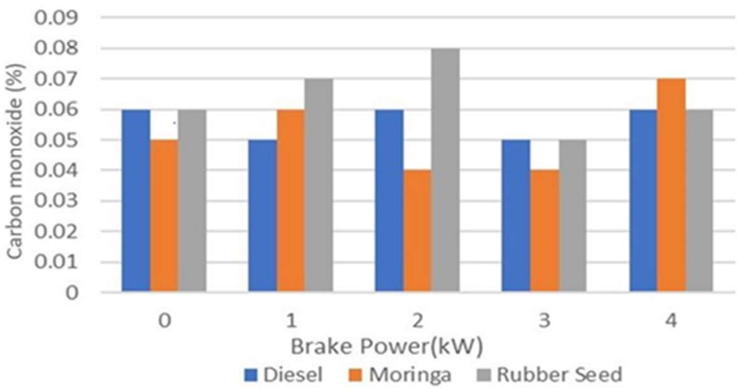

Figure 4. Relationship between CO emission with the BP for diesel and biodiesel blends (RB20 and MO20).

performs is possibly the most remarkable finding. MO20 consistently emits substantially less CO than both diesel and RB20 over all BPs. MO20 and RB20 biodiesel blends have more oxygen and cetane than diesel fuel. Especially with oxygen-rich biodiesel, higher cylinder pressure and temperature facilitate full combustion [9]. This suggests that biodiesel blends might greatly reduce air pollution, particularly CO_2, if used as a fuel.

The BP and UBHC emissions of diesel and MO20 and RB20 biodiesel blends are shown in Figure 5, which clearly shows that for all three fuels, unburned hydrocarbon emissions normally increase with increasing BP. Nonetheless, there are notable differences in the pace of rise among the fuels. When the BP increases, UBHC emissions from diesel fuel rise at the fastest rate, while emissions from RB20 and MO20 fuels are noticeably lower. For instance, RSOME blends exhibit a moderate decrease in emissions of UBHC as compared to diesel, especially at higher BP levels. Reduced HC emissions compared to diesel at rated speed are often the result of better fuel combustion made possible by the oxygen content of MO20 and RB20 [5].

Figure 6 indicates that for all three fuels, NO_x emissions typically increase with the increase in the BP for diesel, RB20, and MO20. The rate of rise, however, shows significant variations throughout the fuels. Diesel fuel is indicated to present the biggest increase of NO_x emissions with the increment in the BP, whereas biodiesel blends, such as RB20 and MO20 fuels, present noticeably lower emissions. More particularly, for a higher BP, NO_x emissions are moderate for RB20 with respect to diesel. NOx emissions also significantly increase with MO20, resulting in a 20% increase in NOx emissions as compared to diesel and a 10% rise in RB20. MOME blends continuously produce significantly less amount of NOx emissions compared to RSOMEs and diesel in the entire range of the BP. It implies that biodiesel blends as fuels can produce a drastic reduction in air pollution, especially concerning NOx. Figure 6 concludes with the fact that biodiesel blends, especially MO biodiesel blends, provide an effective means of reducing the emissions of NOx from diesel engines. Higher NOx emissions for biodiesel blends are due to higher viscosity and density, and have a high cetane number. One major reason why fuel atomization is slower in MO20 and RB20 blends is because of their higher viscosity, which in turn leads to poor air-fuel mixing. The oxygen concentration of *M. oleifera* biodiesel is higher than that of neat diesel fuel. Furthermore, the content of Furthermore, the content of biodiesel in fuel blends is directly correlated to the rise in NO_x emissions. Also, Ozsezen and Canakci [10] reported similar outcomes.

CONCLUSIONS

The research findings strongly indicate that biodiesel, especially from RSO and MO, is a feasible alternative to conventional diesel. The performance characteristics reveal that BSFC for both biodiesel blends (MO20 and RB20 initially

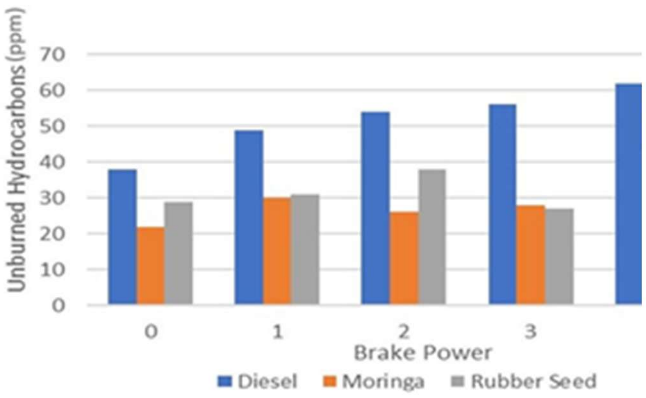

Figure 5. Relationship between HC emission with the BP for diesel and biodiesel blends (RB20 and MO20).

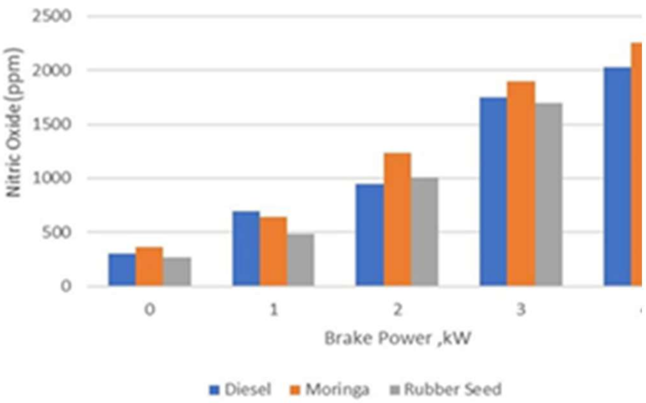

Figure 6. Relationship between NO_x emission with the BP for diesel and biodiesel blends (RB20 and MO20).

exceeds diesel, but as the BP increases, their efficiencies improve. From an environmental standpoint, the reduction in emissions is a significant advantage of biodiesel. CO emissions are markedly lower with biodiesel blends. Diesel emissions are around 0.08% by volume, while MOME blends (MO20) emit significantly less at 0.03%. NO_x emissions also show a substantial increase with MOME blends, producing a 20% rise in NO_x than diesel at a 4 kW of BP. The substantial reductions in harmful emissions, such as up to 60% less CO and 20% more NO_x emissions with MOME blend (MO20) compared to RB20 diesel, RB20 and MO20 biodiesel blends, exhibit lower UBHC emissions compared to diesel by 24% and 28% underscore the environmental benefits. This data is critical for policymakers, manufacturers, and consumers aiming to balance fuel economy with environmental responsibility. Future research should focus on optimizing the blend ratios of RSO and MO biodiesel to further enhance the engine performance and emission characteristics. Detailed studies on specific emissions such as particulate matter, NO_x formation, and after-treatment technologies could provide deeper insights. Additionally, long-term engine durability tests and investigations under varied climatic conditions would be valuable to ensure the practical viability of these biodiesel blends on a larger scale. These findings support the potential of biodiesel, especially MOME blends, as a sustainable alternative for reducing pollution while maintaining competitive engine performance.

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Abbrevations

BP - Brake power

BSFC - Brake specific fuel consumption

BTE - Brake thermal efficiency

BTDC - Before top dead center

CRBME - Crude rice bran oil methyl esters

D5 - 5% diesel in a biodiesel blend

EGT - Exhaust gas temperature

E15 - 15% ethanol and 85% gasoline or diesel

H5 - 5% Hexanol in the fuel blend.

HC - Hydrocarbon

MO - Moringa oil

MOB - Moringa oil biodiesel I

MOBD25 - 25% moringa oil methyl esters blended with diesel fuel

MOME - Moringa oil methyl esters

MO20 - 20% Moringa oil methyl esters blended with diesel fuel

PBDF - Petroleum-based diesel fuel

PM - Particulate matter

RB - Rubber seed oil biodiesel

RSOME - Rubber seed oil methyl esters

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NAUČNI RAD

UPOREDNA ANALIZA BIODIZELA IZ ULJA MORINGE I ULJA KAUČUKOVOG SEMENA U DIZEL MOTORIMA

Energetski resursi se smanjuju, a ekološki problemi postaju sve rasprostranjeniji. U tom smislu, biodizel iz ulja moringe (MO) i ulja kaučukovog semena (RSO) obećava da će biti odlična alternativa dizel gorivima, a istovremeno zahteva daleko manje modifikacije u odnosu na postojeće dizel motore. Analiza performansi otkriva da je potrošnja biodizela nešto veća pri manjim opterećenjima zbog svoje relativno niže kalorijske vrednosti. Pri 4,4 kW, mešavina metil-estara MO (MO20) postigla je termičku efikasnost kočenja od 30%, nadmašujući dizel (26%), dok je mešavina metil-estra RSO (RB20) postigla termičku efikasnost kočenja od 28%. MO20 je smanjila emisiju CO_2 *za 60% u poređenju sa dizelom i 55% u poređenju sa RB20. Međutim, MO20 je povećala emisiju* NO_x *za 10% i 20% pri višim nivoima snage kočenja u poređenju sa RB20 i dizelom, redom. Mešavine biodizela RB20 i MO20 pokazuju niži sadržaj ugljen-monoksida u poređenju sa dizelom za 24% i 28% redom. Ova smanjenja emisija ugljen-monoksida i ugljovodonika čine mešavine biodizela, uglavnom iz MO, čistijim i održivije u poređenju sa konvencionalnim dizelom, sa njihovim ekološkim i performansnim prednostima za primenu u dizel motorima.*

Ključne reči: Biodizel, dizel motor, alternativno gorivo, ulje moringe, ulje kaučukovog semena, emisije.