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Performance Evaluation of Biodiesel Blends from Mahua, Jatropha, and Neem Oils in Diesel Engines: A Comprehensive Review

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A B S T R A C T

In recent years, biodiesel has garnered significant attention due to its beneficial environmental impact. Vegetable oils are prominent sources of biodiesel, providing a renewable energy alternative to fossil fuels. The global dependence on fossil fuels and petroleum products raises economic and environmental concerns, necessitating the development of sustainable energy solutions. Studies have demonstrated the successful use of various vegetable oils, such as rubber seed oil, Mahua oil, Neem oil, and Jatropha curcas oil, as viable biodiesel sources. These biodiesels have shown compatibility with compression ignition engines, improving engine performance and reducing specific fuel consumption. However, prolonged use may affect engine efficiency due to high-viscosity oils forming engine-wax. Comparative research on biodiesel blends derived from Chlorella vulgaris, Jatropha curcas, and Calophyllum inophyllum highlights their potential in reducing emissions of unburned hydrocarbons, carbon monoxide, and particulate matter, although challenges with performance and NOx emissions persist. Various experiments with biodiesel blends in diesel engines have revealed different thermal efficiencies and emissions profiles, emphasizing the need for ongoing optimization to balance performance and environmental benefits. Biodiesel derived from biomass offers a sustainable alternative to fossil fuels, with continued efforts to enhance its performance and reduce its environmental footprint in conventional diesel engines.

Keywords: Biodiesel, Vegetable oils, Engine performance, Emissions, Renewable energy, Mahua, Jatropha, Neem Oil

1. Introduction

Biodiesel, a renewable and environmentally friendly alternative to conventional diesel fuel, has gained significant attention in recent years. It is derived from various feedstocks such as vegetable oils, animal fats, and algae. The production process involves transesterification, where triglycerides present in the feedstock are converted into fatty acid methyl esters (FAMEs). Biodiesel exhibits properties similar to petroleum diesel, making it compatible with existing diesel engines without requiring major modifications. Moreover, it reduces greenhouse gas emissions and contributes to energy security by decreasing dependence on fossil fuels [1]. The day-to-day progress in engine fuel economy and tremendous rise in vehicle numbers have increased demand for gasoline, and in the coming years the petroleum-based fuels would become the most expensive and very scarce. Excessive use and depletion of fossil fuel creates a research interest in the field of alternative fuel technologies. Alternative fuels [2].Mahua biodiesel is a renewable fuel derived from the Mahua tree (Madhuca indica). Its oil content, extracted from the kernel, makes it a potential feedstock for biodiesel production. The process involves esterification to reduce free fatty acids (FFA) and subsequent transesterification. Numerical simulations confirm its viability as an eco-friendly alternative fuel [3]. Jatropha is a fast-growing plant that begins producing oil in its second year and continues to yield for forty to fifty years. Optimal yields are reached from the sixth year onwards. Jatropha curcas, suitable for large-scale wasteland plantations, is a non-edible oil source. It thrives in adverse weather conditions, being drought-resistant and perennial, capable of thriving for up to fifty years in marginal soils. Requiring minimal irrigation, it can grow in various soil types, from coastlines to hill slopes. The seed production of Jatropha averages 0.8 kg per square meter annually. The oil content of Jatropha seeds ranges from 30% to 40% by weight, while the kernel itself varies from 45% to 60%. Fresh Jatropha oil is colourless, slow to dry, and odourless, turning yellow with age. During the Second World War, Jatropha oil was used as a substitute for mineral diesel in Madagascar, Cape Verde, and Benin. Blends of Jatropha oil and diesel were used in diesel engines, exhibiting emission and performance characteristics similar to mineral diesel at low concentrations of Jatropha oil in the mixture [4]. Engines encompass a diverse range of types tailored for specific applications. Internal combustion engines (ICE) dominate automotive and small-scale power generation, with gasoline engines operating on the Otto cycle and diesel engines using compression ignition. Gas turbine engines, including jet engines for aircraft and gas turbines for power plants, excel in high-speed and high-power applications. Steam engines, both reciprocating and turbine-based, historically powered transportation and industrial machinery through the use of steam pressure. External combustion engines like Stirling engines and external combustion piston engines offer unique advantages in efficiency and operation. Electric motors, whether direct current (DC) or alternating current (AC), drive everything from household appliances to electric vehicles, while hybrid engines combine internal combustion with electric propulsion for enhanced efficiency and reduced emissions. Each engine type continues to evolve with technological advancements, striving for greater efficiency, lower emissions, and broader adaptability across various industries and everyday use [5].

2. Comparative Analysis of Biodiesel Blends on Diesel Engines

In recent years, biodiesel has garnered significant attention due to its beneficial environmental impact. Vegetable oils are prominent sources of biodiesel. The escalating global consumption of fossil fuels and petroleum products has raised concerns among countries that heavily rely on crude oil imports. This dependency not only results in substantial foreign exchange outflows but also exacerbates exhaust emissions. Hence, there is an urgent need to develop renewable energy sources (Ramadhas et al., 2005) [6].

Ramadhas successfully demonstrated the operation of a diesel engine using rubber seed oil, confirming its compatibility without issues in compression ignition engines . The use of biodiesel as an alternative to conventional diesel has been advocated , emphasizing its potential benefits

Research findings indicate that Mahua oil, when esterified, increases its viscosity and cetane number, leading to smoother engine performance and a slight enhancement in thermal efficiency while reducing specific fuel consumption . However, prolonged use may decrease engine efficiency due to the formation of engine-wax from high-viscosity oils (Ramadhas et al., 2005).

Studies comparing various biodiesel blends derived from Chlorella vulgaris, Jatrophacurcus, and Calophyllum inophyllum highlight their potential as sustainable fuels, showing lower emissions of unburned hydrocarbons, carbon monoxide, and particulate matter compared to fossil diesel. Nevertheless, challenges such as performance and NOx emissions remain to be addressed.

Experiments using different blends (MB10, MB20, JB10, JB20, PB10, PB20) with diesel in single-cylinder four-stroke engines demonstrated varying thermal efficiencies and emissions profiles. Notably, third-generation fuels (MB10, MB20) showed increased emissions of unburned hydrocarbons and CO compared to second-generation fuels (JB10, JB20, PB10, PB20). Moreover, nitrogen oxide emissions were significantly higher in both third- and second-generation fuels relative to diesel (Sharma et al., 2020) [7].

Overall, biodiesel derived from biomass presents a sustainable alternative to fossil fuels, albeit with ongoing efforts to optimize its performance and environmental footprint in conventional diesel engines.

(Raj, Dugala, and Goindi, 2020)[8] The use of biodiesel has been shown to deplete fossil fuel reserves and increase greenhouse gas emissions. Biodiesel, derived from vegetable oils and animal fats, is considered a green fuel. This research aims to explore the development of biodiesel and examine its fuel properties. Neem seeds contain 30-40 percent oil, and a two-stage transesterification process is used to produce raw Neem oil biodiesel. Motor performance and emission testing were conducted with various biodiesel blends (B10, B20, B30) on an engine with a variable compression ratio (VCR).

(Krishania et al., 2020)[9] This paper investigates exhaust emission parameters using blends of Jatropha, tire pyrolysis oil, and spirulina microalgae biodiesel in a diesel engine with a rated power of 3.5 kW at 1500 rpm. The engine operated at a fixed compression ratio of 17.5 under different load conditions. Measurements included brake thermal efficiency (BTE), fuel consumption, exhaust temperature, sauter mean diameter, and emissions of smoke, particulate matter (PM), nitrogen oxides (NOX), and carbon dioxide (CO2). The secondary blends (JMETPO20, SP20) significantly reduced smoke, PM, and NOX emissions while increasing CO2 emissions. Results showed a reduction in smoke emissions by 11.58% and 18.33%, PM emissions by 5.3% and 33.1%, and NOX emissions by 10.2% and 10.66%, respectively, for JMETPO20 (80% JME + 20% TPO) and SP20 (80% diesel + 20% spirulina) at full load. The numerical and experimental results were consistent for traditional diesel engines, using a fuel injection pressure of 220 bar. Validation was conducted using experimental findings and the proposed numerical solver.

(Rajak et al., 2019)[10] The steady-state operation of diesel engines for commercial applications, transportation, and industry has exacerbated the petroleum-related fuel crisis. Compression ignition engines emit toxic pollutants. This study evaluated the efficiency, combustion, and emissions of aegle methyl ester (AME) biodiesel-diesel blends in a single-cylinder, four-stroke, direct injection diesel engine under various loads using Diesel-RK software at a constant injection timing and speed of 1500 rpm. The B20 blend of AME biodiesel was tested to enhance the use of AME biodiesel in diesel engines. NOX emissions from AME biodiesel blends were higher than those from diesel, but smoke and PM emissions were lower. At maximum engine load, the cylinder pressure for AME20 was higher than that of diesel. Results showed that AME20 biodiesel had approximately 3.72%, 4.2%, 3.52%, 6.68%, and 17.0% lower thermal efficiency, peak heat release rate, exhaust gas temperature, pressure increase, and ignition delay, respectively, and about 3.16%, 1.4%, and 8.5% higher specific fuel consumption, cylinder peak pressure, and sauter mean diameter, respectively, compared to full-load diesel. PM and smoke emissions for the AME20 biodiesel blend were reduced by 17.2% and 20.8%, while NOX emissions were 8.5% higher than diesel emissions. The AME20 biodiesel blend performed better at a higher fuel injection pressure of 220 bar and full load conditions, delivering acceptable engine characteristics.

(Pham, 2019)[11] With the advancements in technology and computer science, it has become easier to use computer software for solving technical problems related to engine dynamics and combustion. However, small researchers and those in developing countries, such as Vietnam, face challenges due to the high cost and limited accessibility of commercial software packages. Diesel-RK is a valuable open-source software for young researchers, as it is free and capable of effectively simulating diesel engine combustion and thermodynamics. This paper presents the results of using Diesel-RK to simulate combustion and fuel injection for a marine diesel engine operating on a homogeneous mixture of ultra-low sulfur diesel (ULSD) and biodiesel derived from palm oil (BO). The numerical simulations analyzed power, pressure, and temperature criteria in the engine combustion chamber, providing useful data on soot and NOX emissions when using five fuel types: ULSD, ULSD-B5, ULSD-B10, ULSD-B20, ULSD-B50, and ULSD-B100.

(Rajak and Verma, 2018a)[12] In recent years, numerous researchers have conducted studies on unconventional fuels through experimental work and numerical simulation. The depletion of fossil fuels has created a global energy consumption crisis, prompting researchers to focus on renewable energy sources like biodiesel, which are less environmentally harmful. This paper aims to reduce pollution parameters such as NOX, smoke, particulate matter (PM), and overall pollution (SE) from five different categories: edible and non-edible vegetable oils, animal fats, waste oil, and biodiesel alcohol. Using a Diesel-RK model, two experimental validations were performed on a single-cylinder, direct injection diesel engine at constant advanced injection timing and diesel speed. Numerical research revealed the most polluting NOX emissions for soybean (edible) at 21.79%, jojoba curcas (non-edible) at 23.0%, chicken fats (animal fats) at 31.2%, grease oil at 15.8%, and butanol at 94.56%. PM emissions were reduced by 45.59%, 84.97%, 93.78%, 23.83%, and 48.18% for soybean, microalgae, poultry fats, frying oil, and pentanol, respectively. Smoke emissions were reduced by 93.8%, 93.43%, 92.26%, 89.14%, and 79.14% for sunflower, karanja oil, fish oil, frying oil, and pentanol, respectively. The most effective emissions summary (SE) decreased by 3.91%, 15.66%, 43.37%, 3.01%, and 37.65% for soybean, jojoba curcas, veal oil, grease oil, and pentanol, respectively, with unchanged injection timing and compression ratio at full load and engine rpm.

(Rajak and Verma, 2018b)[13] This study investigates the characteristics of emulsion fuel with a B20 blend concentration of microalgae spirulina biodiesel (MSB) and its effects on the output, combustion, and exhaust emissions of a direct injection diesel engine. The engine was tested at three different speeds using Diesel-RK commercial software, analyzing parameters such as basic fuel consumption, thermal performance, exhaust gas temperature, ignition delay, heat release rate, particulate matter emissions, carbon dioxide, nitrogen oxides, and smoke emissions. Research was conducted on a single-cylinder, naturally aspirated diesel engine using diesel (B0), MSB-B20 (80% diesel + 20% spirulina), and spirulina biodiesel (B100) at full load. Results show that MSB-B20 reduced cylindrical strength, brake thermal performance, indicated thermal efficiency, particulate matter, nitrogen oxides, and smoke emissions by 1.63%, 1.2%, 0.55%, 10.5%, 6.2%, and 2.6%, respectively. MSB-B20 also improved various fuel consumption parameters, peak heat release rate, ignition delay time, and carbon dioxide emission by 5.08%, 4.5%, 2.45%, and 2.7%, respectively, at 1500 rpm with 100% engine load. These findings were validated against experimental results conducted under the same operating conditions.

(Xu et al., 2017)[14] The goal of this study is to examine the effect of fuel supply parameters such as Fuel Injection Pressure (FIP), Start of Injection Timing (SOI), and Pilot-main Injection Intervals (PMII) on the efficiency and emission characteristics of a 20% blend of Jatropha curcas biodiesel (J20) under light load conditions in a diesel engine. The experiments were designed using Response Surface Methodology (RSM) fractional factorial design. Variance analysis (ANOVA) identified statistically significant multiple regression models for measured responses such as nitrogen oxides (NOX), soot, hydrocarbons (HC), Brake Specific Fuel Consumption (BSFC), and Brake Thermal Efficiency (BTE). Interactive effects between FIP, SOI, and PMII were analyzed using response surface graphs fitted with the RSM model. Optimization was achieved using the RSM's desirability strategy to simultaneously lower emissions and BSFC while enhancing BTE. For a test engine of 21 kW at 1800 rpm, the optimal values for J20 were a FIP of 134.11 MPa, an SOI of 6.4° BTDC, and a PMII of 5.8° CA. The study found that NOX, soot, HC, BSFC, and BTE values with a high desirability of 96.7% at optimum input parameters were 603.44 ppm, 0.037 FSN, 12.73 ppm, 233.26 g/kWh, and 37.31%, respectively.

(Soni and Gupta, 2016)[15] This study outlines a two-stage approach to achieving higher pollution reduction levels to meet stricter emission standards. In the first stage, an optimum blend of diesel and methanol fuel was determined using numerical simulation to maximize the reduction of NOx and soot. In the second stage, numerical analysis was conducted using three different emission reduction approaches: varying the swirl ratio, adjusting the amount of exhaust gas recirculation (EGR), and adding water in different proportions to the optimum diesel-methanol blend to further reduce emissions. The numerical simulation was performed on a single-cylinder Kirloskar diesel engine (TV1 model) using AVL FIRE CFD software. Starting with the optimum diesel-methanol blend as the base fuel, the effects of varying the swirl ratio (1.0, 1.3, 1.6), EGR (10% and 20%), and water addition (5% and 10%) were analyzed. The results showed that the water blend method reduced NOx emissions by 95% and soot by 14% compared to base fuel emissions.

(Bharathiraja, Venkatachalam, and Tiruvenkadam, 2016)[16] This paper explores a low-cost exhaust gas treatment process called water-scrubbing. An emission treatment system was developed and mounted on the engine exhaust. This system sprays water into the exhaust gas, which then passes through a container filled with silica gel. The study experimentally investigates the performance and emission characteristics of a direct injection (DI) diesel engine using diesel fuel (DF), a diesel-Karanja oil blend (DKB), and a diesel-Jatropha oil blend (DJB), with and without water injection in the exhaust. The post-treatment system helps to minimize NOx, CO, and particulate matter emissions. The engine performance was also monitored to determine if there was any decline while using the configuration, and it was noted that engine performance did not improve.

(Ngayihi Abbe et al., 2015)[17] Modern diesel engines running on alternative fuels require reliable models to predict their operating characteristics under various load conditions. While many diesel engine models exist, 0D phenomenological models offer the advantage of quick and accurate computed results. These models are useful for analyzing fuel spray characteristics and instant combustion conditions. This work reports the development, validation, and implementation of a 0D phenomenological model for simulating diesel engine combustion using Neem methyl ester biodiesel (NMEB). The model's relative error is 10% for Sauter diameter, 12% for maximum penetration, 9.8% for peak pressure, 7.38% for peak temperature, 10.7% for NOx emissions, and 13.7% for engine power output. The model predicts a larger Sauter mean diameter, higher fuel spray volume, and NMEB NOx emissions compared to conventional diesel fuel, which aligns with experimental results from previous biodiesel studies. Methyl butyrate and methyl butanoate were used as surrogates for NMEB, with similar results obtained regardless of the surrogate. The average sampling rate for a full cycle simulation was approximately 94.22 seconds, demonstrating the model's utility for optimizing diesel engines. The results were considered satisfactory in terms of precision, algorithm simplicity, and computational cost.

(Kattimani et al., 2015)[18] This study examined the fuel properties of Neem oil methyl ester and its mixtures with conventional diesel oil in proportions of 20:80 (B20), 40:60 (B40), 60:40 (B60), and 80:20 (B80). It was found that fuel properties deviated more from those of diesel oil as the percentage of methyl ester in the blend increased. The B20 blend properties were found to be very close to those of conventional diesel oil. Neem oil methyl ester was also mixed with domestic kerosene oil and conventional diesel oil in ratios of 20:75:5 (B20K5), 40:50:10 (B40K10), 60:25:15 (B60K15), and 80:0:20 (B80K20).

(Merlin et al., 2015)[19] The increase in oil prices invariably leads to higher costs of consumer goods and commodities, significantly affecting the most impoverished populations. This scenario highlights the appeal of renewable energies like biodiesel, which offer a sustainable and easily extractable alternative to fossil fuels. Neem, with its minimal impact on food safety, is considered a suitable raw material for ester production through esterification. This study aims to extract and esterify oil from Neem fruits to produce biofuel, which is then tested under Direct Injection (DI) diesel conditions. The laboratory-produced Neem Methyl Ester (NME) was assessed and found to have chemical and physical properties similar to conventional vegetable oil esters, with the lowest acceptable values. Oil extraction yield was 27.5%, with a low calorific value (LCV) of 38.7 MJ/kg. Chloride and potassium content were measured at 61.00 and 2.19 mol-1, respectively, within acceptable thresholds. Key pollutants, including CO, CO2, and unburned hydrocarbons, were found to be at acceptable levels. NME was tested under the same combustion conditions as petroleum-based fuels using a single-cylinder DI diesel engine, showing reasonable efficiency compared to diesel fuel. The highest CO emission recorded for NME combustion was 698 mg/kg, 18.83% lower than diesel. However, NOx emissions from Neem were 5.64% higher than diesel at the same load level.

(Al-Dawody and Bhatti, 2014)[20] This theoretical and experimental study evaluated a single-cylinder, direct injection diesel engine running on various mixtures of soybean methyl ester (SME) with diesel fuel. The study measured the effects on cylinder pressure, heat release rate, carbon monoxide (CO), unburned hydrocarbons (UHC), nitrogen oxides (NOx), and smoke opacity. Results indicated that biodiesel use resulted in up to 48.23% lower smoke emissions, with a 14.65% higher brake-specific fuel consumption (BSFC) compared to diesel. CO emissions for B20 and B100 SME were 11.36% and 41.7% lower than diesel emissions, respectively. All SME blends produced significantly lower UHC concentrations over the entire load range compared to gasoline. However, NOx emissions were higher for all SME blends. Experimental results showed strong agreement with Diesel-rk software simulations.

(Paul, Datta, and Mandal, 2014)[21] This study investigated the effects of adding jatropha biodiesel to mineral diesel on the performance and emission characteristics of a conventional compression ignition engine. Experiments were conducted using pure diesel (B0) and pure jatropha biodiesel (JB100), with results compared to Diesel-RK software simulations. The study found that using jatropha biodiesel increased brake-specific fuel consumption (BSFC) and reduced brake thermal efficiency. Experimentally, pure diesel had a maximum efficiency of 29.6%, while pure biodiesel's maximum efficiency was 21.2%. Simulations showed maximum efficiencies of 30.3% for pure diesel and 27.5% for pure jatropha biodiesel. Both experimental and simulation results indicated that NOx emissions increased with load and biodiesel use. Further simulations with pure diesel (B0), pure jatropha biodiesel (JB100), and a 50% jatropha blend (JB50) revealed that BSFC increased and brake thermal efficiency decreased with higher biodiesel proportions. Combustion characteristics showed increased peak cylinder pressure and reduced ignition delay with more biodiesel in the blends, while NOx and CO2 emissions increased, and smoke and PM emissions decreased.

(Ashraful et al., 2014)[22] The rapid industrial development, population growth, urbanization, and economic growth have significantly increased energy demand, leading to higher fossil fuel consumption and environmental harm. Biodiesel from non-edible vegetable oils offers a potential solution. This paper reviews non-edible species, including Pongamia pinnata (karanja), Calophyllum inophyllum (polanga), Hevea brasiliensis (rubber seed), Madhuca indica (mahua), cotton seed, Simmondsia chinensis (jojoba), Nicotiana tabacum (tobacco), Azadirachta indica (neem), Jatropha curcas (jatropha), and Linum usitatissimum (linseed), as biodiesel sources. Various aspects such as biology, distribution, chemistry, physicochemical properties, and effects on engine performance and emissions are examined. Fuel properties vary significantly among these feedstocks. Performance reviews revealed that most biodiesels offer higher thermal brake efficiency and lower brake-specific fuel consumption. Emission results showed increased NOx emissions and decreased HC, CO, and PM emissions. The research confirmed that diesel engines could operate successfully with these biodiesels, with outstanding performance and controlled emissions using karanja, mahua, rubber seed, and tobacco biodiesel and their blends.

(Krishna, Bandewar, and Dongare, 2014)[23] This experimental study evaluated a 4-cylinder 39 kW gen-set diesel engine using petrol, karanja oil, and a karanja oil-diethyl ether (DEE) mixture as primary fuels. Outcomes on brake thermal efficiency, fuel consumption, and emissions (unburnt hydrocarbon (HC), carbon monoxide (CO), and NOx) are presented. The study highlights engine performance with different blended fuel substitutions under various load conditions. Using a 25% DEE mixture with karanja oil, the brake thermal efficiency was 26.73% compared to 23.21% for karanja oil and 27.01% for diesel. CO emissions for 25% DEE blends with karanja oil were 0.045% per volume compared to 0.055% for pure karanja oil and 0.035% for diesel. NOx emissions for 25% DEE blends with karanja oil were 265 ppm compared to 347 ppm for karanja oil and 488 ppm for diesel. HC emissions for 15% DEE blends with karanja oil were 27 ppm compared to 44 ppm for karanja oil and 29 ppm for diesel.

(Mohamed F. Al-Dawody, 2013)[24] The rising cost and depletion of fossil fuels have driven researchers to explore vegetable oils, both edible and non-edible, as potential alternatives to petro-diesel fuels. This study developed a detailed computer code using "Fast Basic" language to research the combustion and performance characteristics of a single-cylinder, four-stroke, direct-injection diesel engine with variable compression ratio. The engine operated on diesel fuel combined with 20% ethanol (by mass) biodiesel from soybean oil. Combustion features such as cylinder pressure, heat release percentage, heat transfer, and efficiency features such as brake power and brake-specific fuel consumption (BSFC) were examined. Properties at each crank angle degree were determined based on the first law of thermodynamics, using the Wiebe function to calculate the instantaneous heat release rate. The measured results were validated against the Diesel-rk simulation program.

(Al-Dawody and Bhatti, 2013)[25] This study investigates the combustion, efficiency, and emission parameters of a single-cylinder, four-stroke, constant-velocity diesel engine operating on diesel oil and various soybean methyl ester (SME) blends, both experimentally and theoretically using the Diesel-rk simulation program. With B20, B40, and B100 SME blends, reductions in the Bosch smoke number of 25.27%, 36.93%, and 52.96%, respectively, were observed compared to pure diesel. However, all biodiesel blends produced higher NOx emissions than pure diesel. B20 SME was identified as the optimal blend, offering the best balance between efficiency and emission reduction. Various techniques were implemented to mitigate NOx emissions for B20 SME. A one-dimensional strategy showed that cooling the air temperature from 55°C to 15°C reduced NOx, air pollutants (SE), Bosch smoke number, and brake-specific fuel consumption (BSFC) by 10.53%, 17.63%, 24.35%, and 6.2%, respectively, compared to baseline operations. Utilizing a smaller piston bowl diameter significantly decreased NOx emissions. A two-dimensional scanning technique found that the best reductions in NOx, air pollutants, and Bosch smoke numbers were 22.84%, 20.2%, and 8.31%, respectively, while BSFC increased by 5.14% at a compression ratio of 19 and an exhaust gas recirculation (EGR) ratio of 0.06. The Rosenbrok method was used for multiparametric optimization of the engine running on B20 SME, achieving a 50.26% reduction in NOx emissions. The theoretical simulation results were validated with experimental analysis under similar operational conditions.

(Cristóvão et al., 2012)[26] The fish canning industry faces significant environmental challenges due to high water usage and high levels of organic matter, oil, grease, and salt in its wastewater. This study assessed several plants north of the Douro River in Portugal to propose solutions for these issues. Initially, pollution reduction and control strategies were implemented to reduce water consumption, wastewater output, and pollutant load. The treatability of wastewater was then evaluated through sedimentation and coagulation-flocculation processes using two organic coagulants, RIPOL 070 and RIFLOC 1815. Sedimentation experiments showed that 54% of oils and greases floated and 36% of total suspended solids were removed. The coagulation-flocculation process yielded good results, particularly in terms of oil and grease removal and suspended solids reduction. The best removal efficiencies for suspended solids were 53% with 400 mg/L of RIPOL 070 and 79% with 150 mg/L of RIFLOC 1815. Both coagulants demonstrated excellent oil and grease removal, achieving about 99% for RIFLOC 1815 and 88% for RIPOL 070.

(Al-Dawody, 2011)[27] This research aimed to investigate the efficiency and emissions of a single-cylinder, four-stroke, direct injection diesel engine operating on diesel oil and various Soybean Methyl Ester (SME) blends using the Diesel-RK simulation program. Results showed that with B20, B40, and B100 SME blends, the Bosch smoke number decreased by 41.3%, 53.2%, and 62.6%, respectively, compared to pure diesel. Particulate matter (PM) emissions were reduced by 47.2%, 60%, and 68% for B20, B40, and B100 SME blends, respectively. Thermal efficiency, power, and specific fuel consumption (SFC) decreased by 2%, 3%, and 12%, respectively, for all SME blends compared to pure diesel. NOx emissions were over 28% higher for all SME blends compared to pure diesel. A parametric study of injection timing, engine speed, and compression ratio effects indicated that delaying injection timing significantly reduced NOx emissions. Among all tested fuels, B20 SME was the best, delivering comparable performance with reduced emissions compared to pure diesel. The results aligned well with findings from other researchers and theoretical and experimental data.

(Öner and Altun, 2009)[28] This study explored the usability of inedible animal tallow as a substitute fuel for diesel engines, testing it as pure biodiesel and in blends with petroleum diesel fuel. Tallow methyl ester was prepared by base-catalyzed transesterification with methanol using NaOH as a catalyst. Fuel properties of the methyl ester, diesel fuel, and their mixtures (5%, 20%, and 50% by volume) were determined, meeting ASTM D6751 and EN 14214 specifications. The viscosity and density of tallow methyl esters were close to those of diesel, with a slightly lower calorific value. Experimental research showed that biodiesel reduced engine efficiency but increased real fuel consumption due to its lower heating value compared to diesel. However, biodiesel was equivalent to diesel in engine capacity. Tallow methyl ester (B100) reduced emissions of CO, NOx, SO2, and smoke opacity by 15%, 38.5%, 72.7%, and 56.8%, respectively, compared to diesel. Among the fuels tested, B20 had the lowest CO and NOx emissions and the highest exhaust temperature. The reductions in exhaust emissions made tallow methyl esters, particularly B20, a viable alternative fuel for diesel, potentially aiding in air pollution control. The study concluded that tallow methyl esters and their blends could replace diesel in direct injection diesel engines without modifications.

(Kuleshov and Mahkamov, 2008)[29] A refined mathematical model for the multi-zone diesel fuel spray combustion process in compression ignition engines was presented to extend its capability to explain the operation of diesel engines on various biofuel blends. Numerical simulations of a Caterpillar diesel engine running on diesel oil and soybean methyl ester (SME) blends were conducted. The theoretical findings for SME blends of 20% and 40% showed strong agreement with published experimental data. The proposed model reliably estimated the heat release rate during combustion and the levels of NOx and PM emissions, demonstrating its utility for optimizing engine design and operational parameters.

3. Conclusion

The comprehensive review of biodiesel blends derived from Mahua, Jatropha, and Neem oils for use in diesel engines reveals several critical insights into their performance, efficiency, and emission characteristics. The following conclusions can be drawn from the evaluation:

Performance Efficiency: Biodiesel blends from Mahua, Jatropha, and Neem oils generally show a slight decrease in brake thermal efficiency compared to pure diesel. However, the performance remains within acceptable limits, indicating the feasibility of using these biodiesel blends in diesel engines without significant modifications.Among the blends, B20 (20% biodiesel and 80% diesel) often provides the best balance between maintaining engine performance and reducing emissions.

Fuel Consumption: The brake-specific fuel consumption (BSFC) tends to be higher for biodiesel blends due to their lower energy content compared to diesel. This increase is more pronounced at higher blend ratios but remains manageable at lower blend levels such as B20.

Emission Characteristics: Biodiesel blends significantly reduce emissions of carbon monoxide (CO), unburned hydrocarbons (UHC), and particulate matter (PM) compared to pure diesel. This reduction is beneficial for mitigating air pollution and enhancing environmental sustainability. However, the use of biodiesel blends results in higher nitrogen oxide (NOx) emissions. This is a common challenge with biodiesel and necessitates further research and development of strategies to mitigate NOx emissions, such as optimized engine tuning, exhaust gas recirculation (EGR), and the use of catalytic converters.

Environmental Impact: The use of non-edible oils like Mahua, Jatropha, and Neem for biodiesel production is environmentally advantageous as it avoids the food vs. fuel debate and utilizes resources that are otherwise underutilized. The cultivation of these oil-producing plants can also contribute to rural development and provide economic benefits to local communities.

Optimization and Future Research: Ongoing research should focus on optimizing biodiesel production processes to enhance fuel properties and reduce production costs. Further studies on engine modifications, advanced fuel injection systems, and after-treatment technologies are essential to address the NOx emission challenge. Life cycle analysis and sustainability assessments should be conducted to fully understand the long-term impacts of biodiesel use on both the environment and the economy.

In conclusion, biodiesel blends from Mahua, Jatropha, and Neem oils present a promising alternative to conventional diesel fuels. They offer significant environmental benefits and can help in reducing dependence on fossil fuels. Continued research and technological advancements will be key to maximizing their potential and overcoming the existing challenges associated with their use in diesel engines.

4. Future Scope

Moving forward, the future scope of research on biodiesel blends from Mahua, Jatropha, and Neem oils in diesel engines includes optimizing engine designs to better accommodate biodiesel properties and enhance efficiency. There is a need for continued development of advanced emission control technologies to further reduce CO, NOx, and particulate matter emissions during biodiesel combustion. Improvements in feedstock quality and yield through breeding, genetic modification, or cultivation techniques will be crucial. Innovations in biodiesel production processes are necessary to streamline efficiency, reduce costs, and minimize environmental impact. Exploration into alternative biodiesel feedstocks beyond Mahua, Jatropha, and Neem oils will offer options with improved sustainability and performance characteristics. Lifecycle assessment studies are essential to understand and mitigate the environmental impacts of biodiesel production, distribution, and use. Strategies to increase market acceptance and adoption of biodiesel blends, supported by favorable policies and incentives, will play a pivotal role. Integrating biodiesel production with other renewable energy systems can create synergistic solutions for sustainable energy production and environmental stewardship.

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