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Original Article

An Experimental Study on the Influence of Antioxidant on Nitrous Oxide Emission in Compression Ignition Engine Utilizing Kenaf Biodiesel Blends

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Abstract

Biodiesel is considered as a prominent replacement for fossil fuels. In spite of its advantages, feedstock cost and competition with the food chain are said to be the main drawbacks. The present investigation focuses on identifying a feedstock that does not compete with the food chain. Common second-generation feedstocks are suggested to be a prominent source for biodiesel production as they involve the use of trash seeds. Moreover, the oil recovered from such seeds is non-edible. Considering these facts, the present work employs kenaf seeds as a feedstock for biodiesel production and its emission traits are determined on a compression ignition engine of 5.2 kW. The results of the investigation revealed that the feedstock seeds have an oil content of 31%. It is also observed from the investigation outcomes that the biodiesel proportion blend (B25) outperformed in terms of tail emission except nitrogen oxides (NO_x). At peak load, the carbon monoxide emission is found to be 0.089 (% by volume), while the emission of hydrocarbon and NO_x are 52 and 970 ppm, respectively. In the later phase of investigation, a triacetin antioxidant was dispersed with B25 in varying concentrations. The outcomes revealed that a 0.25 g concentration is optimum, which results in a NO_x emission of 949 ppm.

Categories: Environmental Engineering

Keywords: fossil fuels, second generation feedstock, non-edible, ci engine, emission, antioxidant

Introduction

In view of the rapid depletion of fossil fuel reserves and the escalating concerns regarding environmental degradation, the exploration of renewable and alternative energy sources has become imperative. To address the challenges associated with fossil fuel dependency, a considerable number of researchers have intensified efforts to identify viable alternative fuels. Consequently, attention has increasingly shifted toward renewable energy resources such as solar, geothermal, wind, biofuels, and ocean energy. Among these, biodiesel has emerged as one of the most promising renewable fuels due to its properties being comparable to those of conventional diesel [1]. Owing to its renewable nature, environmental compatibility, and non-toxic characteristics, biodiesel is widely recognized as a suitable substitute for diesel fuel in compression ignition (CI) engines [2]. The growing interest in biodiesel is primarily driven by the depletion of fossil fuels and the rise in greenhouse gas emissions. Biodiesel is a clean-burning and sustainable fuel that can be produced from various vegetable oils [3]. Its inherent advantages, including an oxygenated composition, the absence of sulfur, biodegradability, and renewability, position it as one of the most viable alternative fuels for diesel engines, as supported by recent studies. Furthermore, blends of biodiesel with petroleum diesel offer several advantages, such as reduced exhaust emissions, decreased engine wear, lower lubricant consumption, and thermal efficiency comparable to that of conventional diesel fuel. Extensive investigations have been conducted to evaluate the performance and emission characteristics of biodiesel in diesel engines and to establish its feasibility as an alternative fuel [4]. To date, more than 350 oil-bearing crops have been identified as potential feedstocks for biodiesel production [5]. Despite these advantages, the application of biodiesel in diesel engines is constrained by certain limitations, notably its higher viscosity and inferior low-temperature flow properties [6]. Biodiesel is typically produced through the esterification (transesterification) of vegetable oils, resulting in a highly oxygenated and renewable fuel [7]. In this context, the use of biodiesel-diesel blends, incorporating a moderate proportion of petroleum diesel, has been shown to mitigate air pollution while conserving finite fossil fuel resources without significantly compromising engine performance and fuel economy [8]. Additionally, such blends have demonstrated notable reductions in emissions of CO_2, carbon monoxide (CO), and smoke opacity, albeit with a slight increase in nitrogen oxides (NO_x) emissions [9]. However, due to its higher viscosity and lower calorific value, biodiesel may lead to increased brake specific fuel consumption and comparatively reduced engine performance in CI engines [10]. In recent years, kenaf has gained attention as a potential feedstock for biodiesel production. Kenaf seeds, owing to their relatively high oil content, present an attractive alternative to conventional oilseed crops such as canola and soybean. The kenaf plant (*Hibiscus cannabinus*) is a fast-growing fibrous crop that can reach heights of 12-15 feet and thrives in warm, tropical climates. Traditionally cultivated for its strong and versatile fibers used in textiles, paper, ropes, and biocomposites, kenaf also offers significant potential in the biofuel sector. The seeds typically contain about 30-40% oil by weight, making them a promising source for biodiesel production. Moreover, since kenaf is not a primary food crop, its utilization for biodiesel does not interfere with food supply chains, unlike many conventional feedstocks. Although the majority of biodiesel research has focused on widely used feedstocks such as palm oil, rapeseed, and soybean, the substantial potential of kenaf remains comparatively underexplored. Considering its favorable characteristics and environmental benefits, the present study aims to investigate and elucidate the emission characteristics of kenaf biodiesel blends, thereby contributing to the development of sustainable and efficient alternative fuels.

Materials And Methods

FIGURE 1: Photograph of kenaf seed

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FIGURE 2: Photograph of test engine

Oil extraction from feedstock seed

The seeds of kenaf about 15 kg are gathered from a local market. The seeds are found to contain chaffs and other impurities. To mitigate impurities, the gathered seeds are winnowed and washed with clear water until the color of the water remains neutral. The seeds are then dried in the absence of sunlight for 3 days. This process is said to be shade drying. A mechanical-type oil extractor, which is available in the local market, is employed to extract oil from the pure seeds. The seeds are found to contain 31% of oil on a weight basis. The neat oil appears brownish yellow and has an unpleasant odor. It is also found that the neat oil is highly dense and viscous. Figure *1* depicts the photograph of kenaf seeds.

In general, oil with high density cannot be employed as fuel to run a CI engine, as it results in filter clogging. Furthermore, to reduce the density of neat oil and make it quite suitable to run a CI engine, it is subjected to an appropriate chemical procedure. Alcohol is incorporated into biodiesel to alleviate its high viscosity, which can assist with fuel injection problems [11].

Role of chemical techniques

The main purpose of incorporating a chemical procedure is to lower the density and viscosity of the recovered neat oil. Among several chemical procedures, transesterification is found to be viable, simple, and cost effective. The primary role of transesterification is to transform triglycerides into monoglycerides along with a byproduct with the assistance of appropriate alcohol and catalyst. In the present research work, this process is accomplished with the help of a simple reactor provided with a stirring setup, thermometer, and heating unit. Figure *2* depicts the photograph of the simple reactor. In the present work, methanol is employed as the alcohol, and powdered NaOH is employed as the catalyst. The function of the stirring unit in the reactor is to stir the neat oil and methoxide solution (mixture of methanol and NaOH) at 60°C. The oil: methanol ratio is maintained as 1:6. The function of heating unit is to maintain reaction temperature, and the thermometer is used to record the temperature. The reaction is carried out under constant stirring of 200 rpm for 2 hours. After the completion of reaction, the mixture is shifted to a separate container and kept undisturbed for 12 hours. Two distinct end products including methyl ester of kenaf and glycerol are formed at the end of this process; the glycerol thus formed is isolated and finds its application in cosmetics. It was found that about 250 g of methoxide solution containing 240 ml of methanol and 5 g of NaOH resulted in 78% of methyl ester.

Test blend preparation

The resulting methyl ester is then blended with regular fuel (diesel) in different proportions; this is done to determine the optimum blend. Engine performance and combustion characteristics were significantly enhanced by blending renewable fuels with neat diesel fuel [12]. The test blends include: blend B25-KOME (test fuel containing 25% of kenaf oil methyl ester and 75% of regular fuel), blend B50 (test fuel containing 50% of kenaf oil methyl ester and 50% of regular fuel), blend 75 (test fuel containing 75% of kenaf oil methyl ester and 25% of regular fuel), and neat biodiesel blend (test fuel containing 100% of kenaf oil methyl ester).

Test engine setup

In the present research work, to assess the emission traits of generated biodiesel blends, a 5.2 kW Kirloskar TV1 single cylinder CI engine is utilized, whose bore diameter and stroke length is 87.5 mm and 110 mm. The test engine, in addition, is incorporated with an appropriate exhaust gas analyzer and smoke meter. The exhaust gas analyzer helps in measuring the proportion of tail emission gases, and the smoke meter helps in measuring the density of exhausted smoke. Throughout the investigation, the test engine is allowed to run at 1500 rpm, and the load to the test engine is applied with the help of an electrically operated dynamometer. The load applied to the CI engine is varied from zero to maximum in 20% increments. The operating parameters of the CI engine are set at 210 bar injection pressure, a 17.5 compression ratio, and 24°CA bTDC, respectively. Figure *2* depicts the photograph of the test engine.

Results

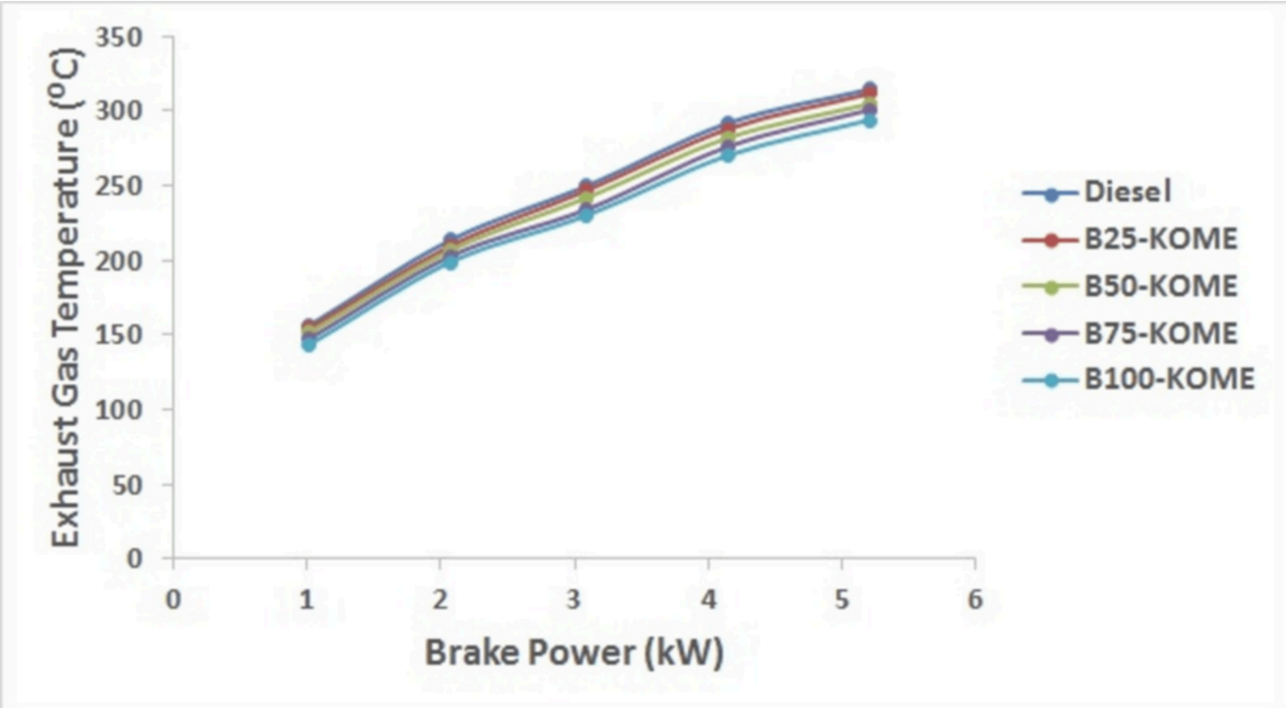

FIGURE 3: Variation of EGT with BP

EGT, exhaust gas temperature; BP, Brake Power

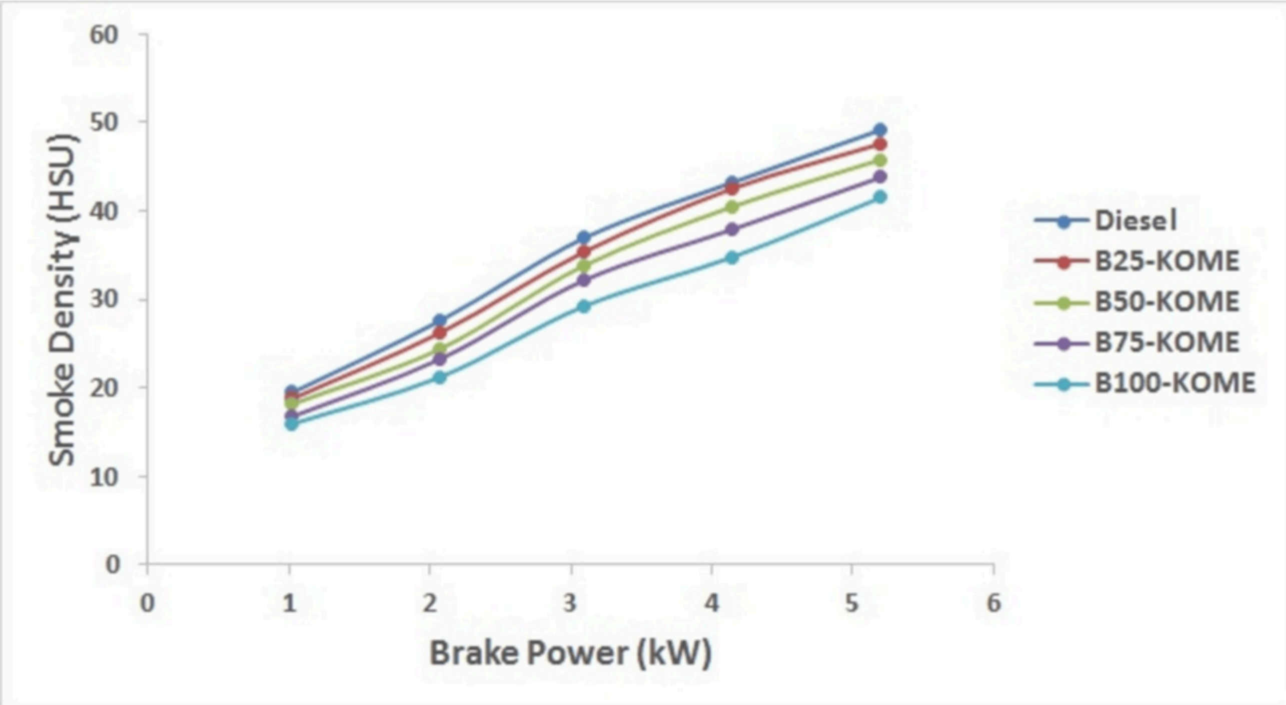

FIGURE 4: Variation of SD with BP

SD, smoke density; BP, Brake Power

The emission traits including exhaust gas temperature (EGT), smoke density (SD), emission of carbon monoxide (CO), emission of hydrocarbon (HC) and emission of NO_x of the conventional fuel and biodiesel blends for each applied load are assessed, compared, and discussed in the preceding section. B20 was the most efficient blend among the others, and that it could replace diesel, thereby decreasing diesel consumption by 20% [13]. By lowering the amount of harmful substances discharged into the atmosphere and significantly improving engine performance, it helps mitigate pollution [14]. B20 has been identified to be the ideal blend for improving engine performance since it shows consistent performance characteristics without requiring any minor modifications to the diesel engine [15].

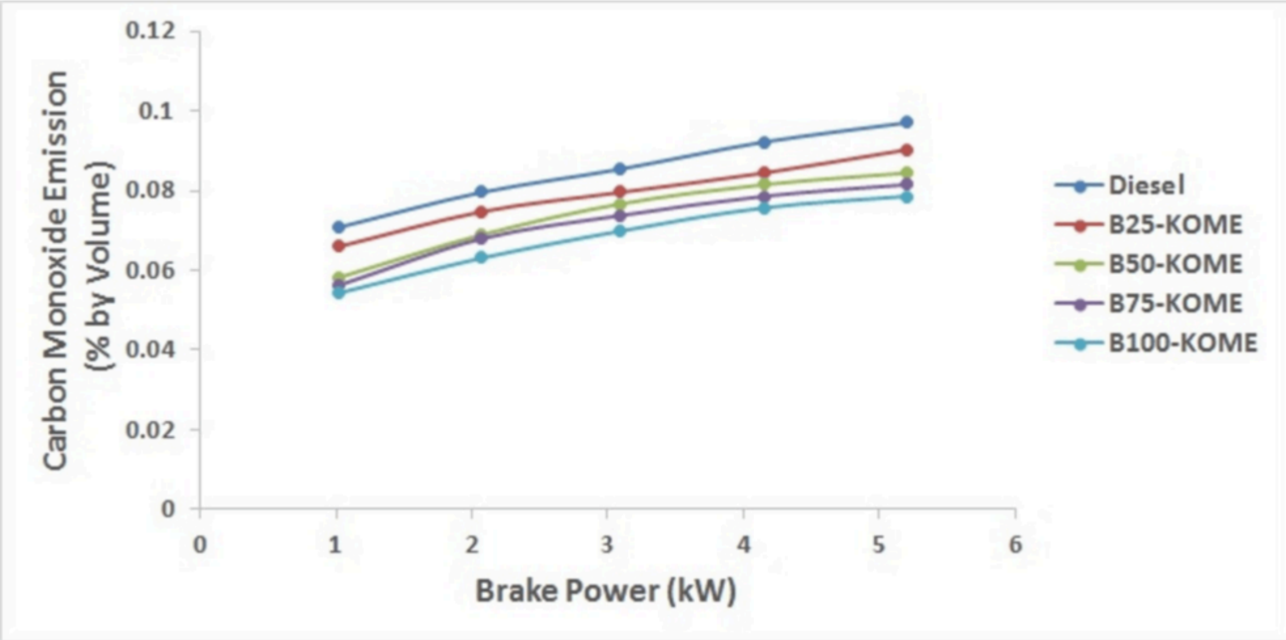

FIGURE 5: Variation of CO with BP

CO, carbon monoxide; BP, Brake Power

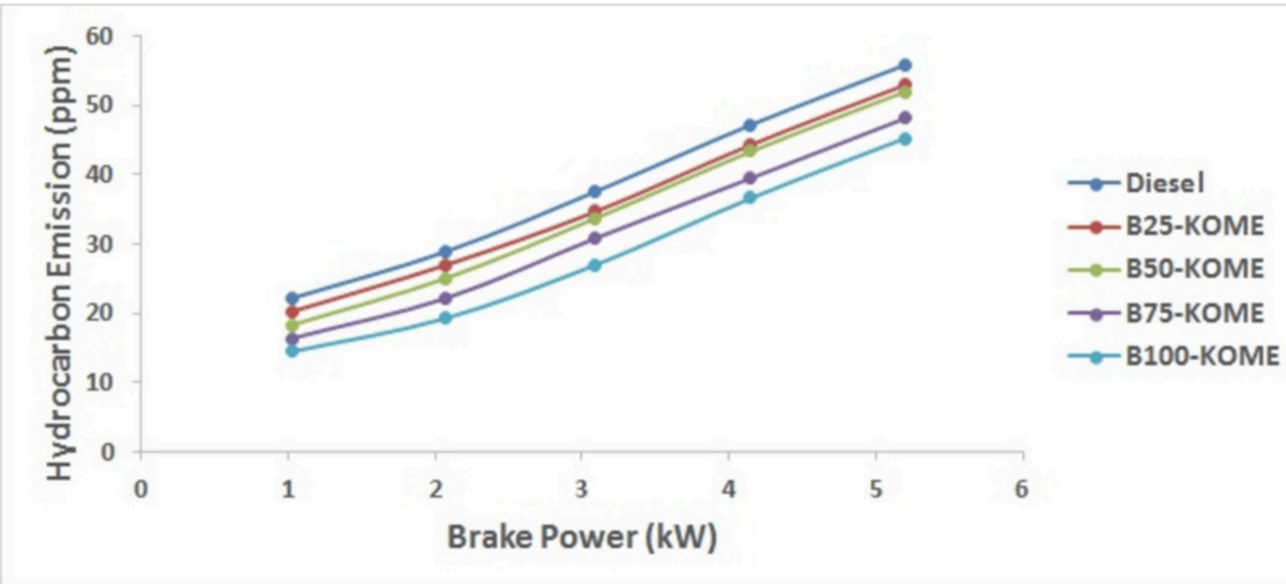

FIGURE 6: Variation of HC emission with BP

HC, emission of hydrocarbon; BP, Brake Power

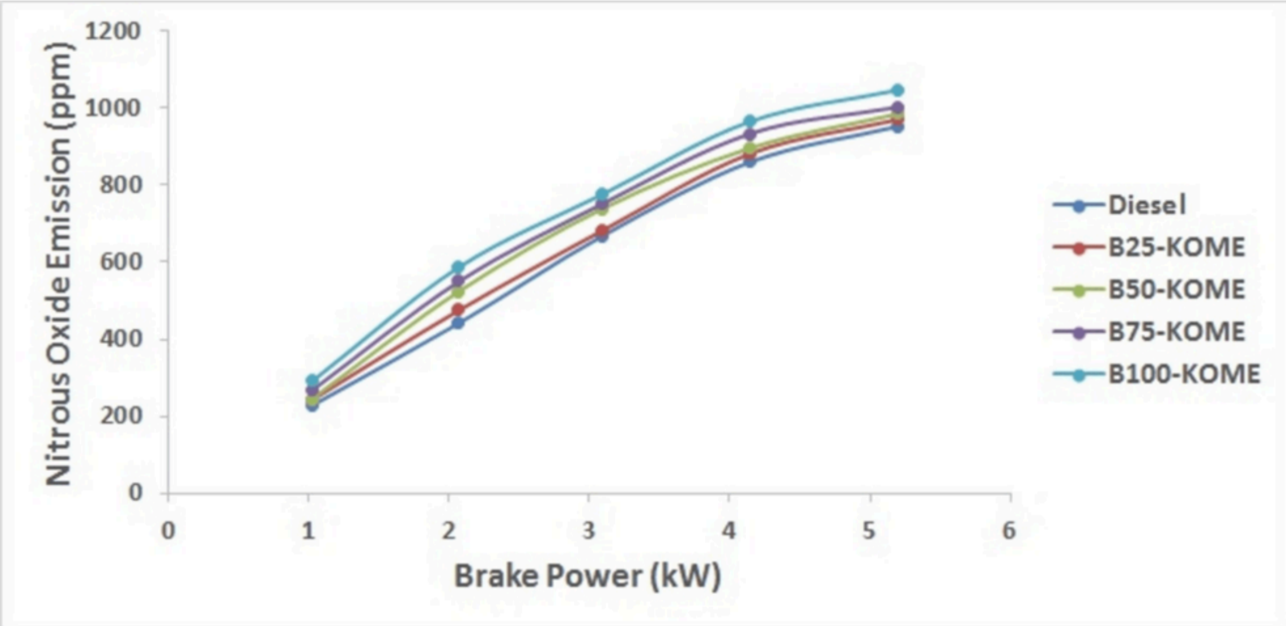

FIGURE 7: Variation of NOX emission with BP

NO_x, nitrogen oxides; BP, Brake Power

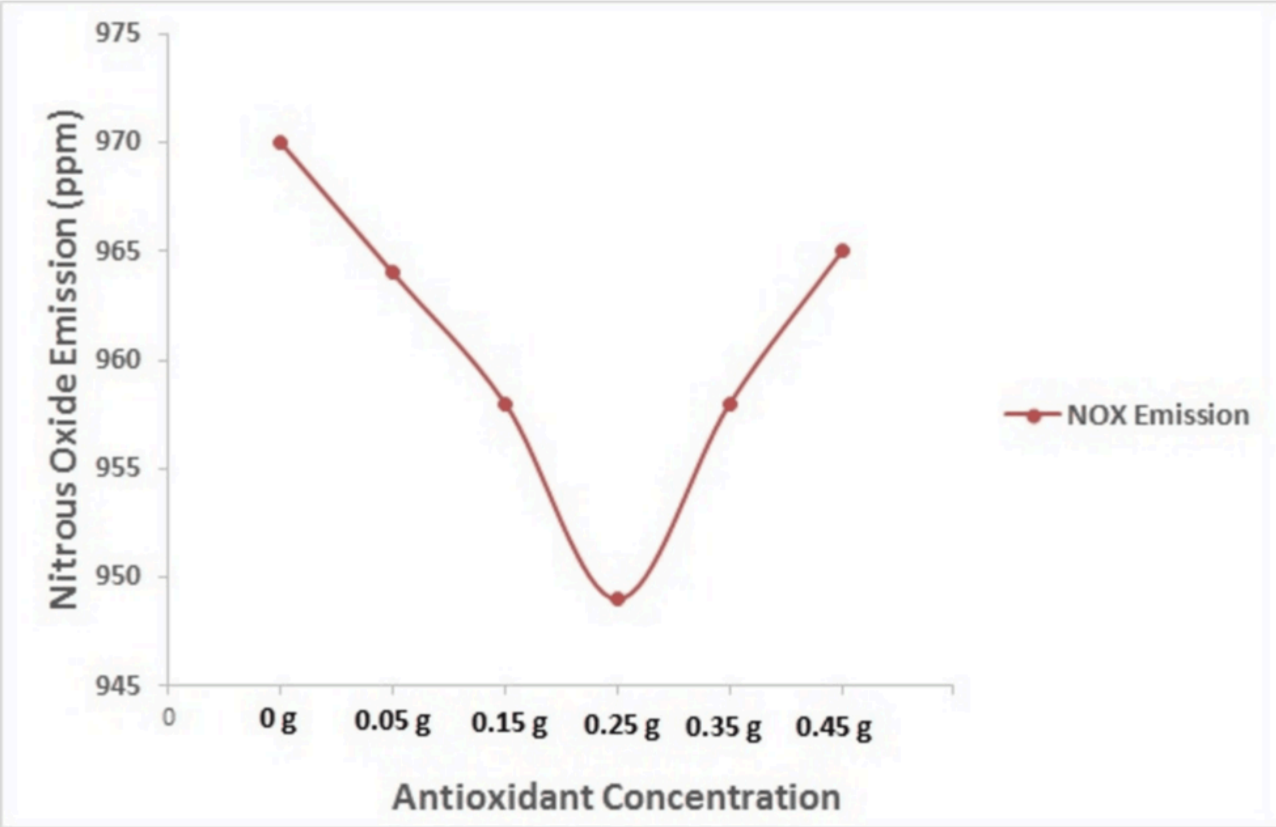

FIGURE 8: NOX emission for varied antioxidant concentration

NO_x, nitrogen oxides

Discussion on result

This research outlines a systematic methodology for the extraction, processing, and assessment of biodiesel derived from kenaf seed oil, aimed at its use as an alternative fuel in CI engines. Mechanical extraction techniques yielded around 31% oil by weight. However, the crude oil exhibited high density, viscosity, and a pungent odor, rendering it unsuitable for direct engine use. To overcome these limitations, a transesterification process was applied using methanol and sodium hydroxide (NaOH), effectively transforming triglycerides into methyl esters and improving the fuel's physical properties. The processed biodiesel was mixed with standard diesel in various proportions including B25, B50, B75, and B100 to evaluate its engine performance and emission characteristics. Among the tested blends, B25 showed the most significant brake-specific fuel consumption (BSFC) and brake thermal efficiency (BTHE). The EGT for B25 was marginally lower than diesel, indicating more complete combustion [13]. Reductions in SD, CO, and HC emissions were observed in all biodiesel blends [14]. Conversely, a slight increase in nitrogen oxides (NO_x) was recorded, a typical consequence of higher in-cylinder temperatures associated with oxygen-rich fuels. To counteract this, triacetin an antioxidant was added to B25 in different concentrations. The use of an ultrasonicator ensured uniform dispersion of the additive. Notably, a 0.25 g concentration of triacetin reduced NO_x emissions by approximately 2.16% at full engine load. The results of investigation outlined the effectiveness of additives in optimizing emission characteristics and support the use of kenaf-derived biodiesel (KOME), especially B25 with triacetin, as a viable and cleaner alternative to conventional diesel [15].

Exhaust gas temperature (EGT)

EGT is said to be the significant parameter which provides clear insight into the rate of fuel combustion. The higher the rate of combustion, the lower will be the EGT of tail emission. The variation of EGT and BP is depicted in Figure *3*.

From the graph, it is found that the EGT of regular fuel is relatively high when compared with the EGT of biodiesel blends. Biodiesels are cleaner combusting fuels, therefore resulting in a lower EGT than the regular fuel. B100 resulted in better EGT performance than the other blends. All of the tested biodiesel diesel blends showed lower levels of EGT and smoke opacity, in accordance with the exhaust emissions [16]. At peak load, the EGT of B25 is found to be 311°C, while for the regular fuel it is 314°C. The relatively high EGT of regular fuel is primarily due to incomplete combustion.

Emission of smoke (SD)

The formation of smoke is considered an undesirable product produced during the combustion of fuels. Similar to EGT, the lower the level of SD, higher will be the rate of combustion. The type of fuel employed and its property have a strong influence on the formation of SD. The variation of SD with BP is depicted in Figure *4*.

It is observed from the graph that regular fuel resulted in a relatively higher SD than the biodiesel blends, which is due to incomplete combustion. As biodiesel blends comprise a significant cetane number, which promotes combustion and results in better combustion, thereby producing relatively lower SD than the regular fuel. At peak load, the SD of the regular fuel and B25 is found to be 50 HSU and 47 HSU, respectively.

Emission of carbon monoxide (CO)

CO is a type of harmful gas produced during the combustion of fuel. The property of fuel employed has a strong influence on the formation of CO. Specific consumption of fuel (SFC), CO, and NO_x emissions all reduced when the proportion of sesame biodiesel blend increased [17]. It had been found that the B5 and B100 fuels produced CO emissions that were 9% and 32% lower, respectively, than the diesel fuel [18]. The variation of CO emission with BP is depicted in Figure *5*.

It is clear from the graph that the biodiesel blends resulted in lower CO emissions than the regular fuel. The decline in the CO emission of biodiesel blends is primarily due to the presence of oxygen molecules, which promotes oxidation and result in the formation of CO_2. The regular fuel, in contrast, does not contain enough oxygen molecules and hence exhibits relatively high CO emission than the biodiesel blends. At peak load, the CO emission of regular fuel is 0.1 (% by volume), while for the blend B25 it is 0.089 (% by volume).

Emission of hydrocarbon (HC)

The rate of combustion and uncombusted fuel components have a strong influence on the formation of HC emission. It is apparent that using biodiesel in diesel engines decreases HC emissions [19]. The variation of HC emission with BP for the test fuels employed is depicted in Figure *6*.

It is clear from the graph that the regular fuel resulted in relatively high HC emission when compared with the biodiesel blends. The presence of significant oxygen molecules in the biodiesel blends results in enhanced combustion, and as a result, mitigates the presence of unburned fuel elements in the combustion zone. Therefore, the biodiesel blends resulted in lower HC emission than regular fuel. The HC emission of regular fuel at peak load is found to be 55 ppm. At the same load, the HC emission of B25 is found to be 52 ppm.

Emission of nitrogen oxides (NO_x)

Similar to CO, NO_x is a sort of harmful emission resulting during the combustion of fuel. The elevated temperature of the combustion zone and the properties of the fuel employed are considered the primary factors in the formation of NO_x. With the exception of nitrogen oxides, exhaust emissions by employing biodiesel blends have been found to be substantially lower than diesel [20]. The fact that biodiesels are cleaner alternative fuels and can be employed directly in diesel engines without any additional modifications has made them quite common [21]. In accordance with the emission results of biodiesel, NO_x is often increased, whereas HC, CO, and PM emissions are lowered [22]. The variation of NO_x emission with BP is depicted in Figure *7*.

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It is observed from the graph that the regular fuel generated relatively less NO_x emission when compared with the biodiesel blends. The significant oxygen molecules available in the biodiesel blends interact with the nitrogen of the intake air and result in the formation of relatively high NO_x emissions. At peak load, the NO_x emission of regular fuel and B25 is found to be 952 and 970 ppm, respectively. The results suggest that lower biodiesel blends offer engine efficiency that is both acceptable and significantly improved. In contrast, emission levels have considerably reduced [23].

Influence of triacetin on NO_x emission

In general, introducing additives to biodiesel blends can help improve certain qualities, such as oxidation stability and cold weather performance, but the impact is mostly dependent on engine design, operational circumstances, and the proportion of additives employed [24]. The performance and emission features of CI engines are significantly improved by additives [25]. In the present work, the ultrasonicator serves to appropriately disperse the triacetin antioxidant substance in the blend B25 in varied proportions. Figure *8* depicts the variation of NO_x with varied triacetin concentration at maximum load.

From the outcomes, it is found that the triacetin has a significant impact on lowering the NO_x emission by mitigating the formation of free radicals and thereby enhancing fuel stability. Among various employed triacetin concentrations, 0.25 g performed best in terms of declining NO_x especially at maximum load. At similar load, the NO_x emission of B25 along with 0.25 g of triacetin is found to be 949 ppm, which is 2.16% less when compared with standard B25.

Discussion

This research outlines a systematic methodology for the extraction, processing, and assessment of biodiesel derived from kenaf seed oil, aimed at its use as an alternative fuel in CI engines. Mechanical extraction techniques yielded around 31% oil by weight. However, the crude oil exhibited high density, viscosity, and a pungent odor, rendering it unsuitable for direct engine use. To overcome these limitations, a transesterification process was applied using methanol and NaOH, effectively transforming triglycerides into methyl esters and improving the fuel's physical properties. The processed biodiesel was mixed with standard diesel in various proportions including B25, B50, B75, and B100 to evaluate its engine performance and emission characteristics. Among the tested blends, B25 showed the most significant BSFC and BTHE. The EGT for B25 was marginally lower than diesel, indicating more complete combustion [13]. Reductions in SD, CO, and HC emissions were observed in all biodiesel blends [14]. Conversely, a slight increase in NO_x was recorded, a typical consequence of higher in-cylinder temperatures associated with oxygen-rich fuels. To counteract this, triacetin an antioxidant was added to B25 in different concentrations. The use of an ultrasonicator ensured uniform dispersion of the additive. Notably, a 0.25 g concentration of triacetin reduced NO_x emissions by approximately 2.16% at full engine load. The results of investigation outlined the effectiveness of additives in optimizing emission characteristics and support the use of kenaf-derived biodiesel, especially B25 with triacetin, as a viable and cleaner alternative to conventional diesel [15].

Conclusions

The experimental findings showed that biodiesel, preferably blended or in neat form may be utilized in CI engines, offering a practical substitute for diesel. Without necessitating any engine modifications, biodiesel could potentially be utilized as an eco-friendly fuel substitute. From the outlines of the present investigation, it is found that the feedstock seed employed has a significant oil content of 30%. The oil extracted from the feedstock seed is nonedible and therefore cannot compete with food supply. The process of transesterification is found to be simpler and cost effective for commercial scale and it resulted in 80% of methyl ester yield. The blend B25 outperformed in terms of emission, except the emission of NO_x. The biodiesel blends resulted in lower CO and HC emission than the regular fuel at all load levels applied. At peak load, the CO and HC emission of regular fuel is found to be 0.1 (% by volume) and 55 ppm. The similar emissions at similar load for B25 is found to be 0.089 (% by volume) and 52 ppm. The NO_x emission of B25 at peak load is 970 ppm, which is relatively high when compared with other blends and regular fuel. Except the emission of NO_x, the biodiesel blends have a strong influence in declining CO and HC emission and promoting combustion. Among the varied concentrations of triacetin antioxidant, 0.25 g is found to be optimum which reduces the NO_x emission by 2.16%. At peak load, the B25 with 0.25g triacetin resulted in relatively lower NO_x emission which is 949 ppm.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: Dinesh Kumar Venkatesan, Vinayak Bhimsen Hemadri, Vinodhkumar Balakrishnan, Vijay Manikandan Manickam Selvaraji, Ganesan Halan

Acquisition, analysis, or interpretation of data: Dinesh Kumar Venkatesan, Vinayak Bhimsen Hemadri, Vinodhkumar Balakrishnan, Vijay Manikandan Manickam Selvaraji, Ganesan Halan

Drafting of the manuscript: Dinesh Kumar Venkatesan, Vinayak Bhimsen Hemadri, Vinodhkumar Balakrishnan, Vijay Manikandan Manickam Selvaraji, Ganesan Halan

Critical review of the manuscript for important intellectual content: Dinesh Kumar Venkatesan, Vinayak Bhimsen Hemadri, Vinodhkumar Balakrishnan, Vijay Manikandan Manickam Selvaraji, Ganesan Halan

Supervision: Dinesh Kumar Venkatesan, Vinayak Bhimsen Hemadri, Vinodhkumar Balakrishnan, Vijay Manikandan Manickam Selvaraji, Ganesan Halan

Disclosures

Human subjects: All authors have confirmed that this study did not involve human participants or tissue. **Animal subjects:** All authors have confirmed that this study did not involve animal subjects or tissue. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

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