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Performance and Emissions Investigation of Biodiesel Made from Neem Oil

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The world's rising industrialization and motorization are blamed for the increased use of petroleum products. Hence, alternative fuels that can be made with locally available materials must be considered. Biodiesel is a liquid fuel, similar to diesel, created from biological sources that are renewable. Methyl esterification is a process that may turn any type of vegetable oil or animal fat into biodiesel, which is subsequently suitable for use in diesel engines. Our present investigations aims to examine the difficulties in producing biodiesel from neem oil and look into the characteristics of the fuel, which is fully made of mono alkyl esters produced by the transesterification process. For this purpose, a single cylinder, four-stroke, kirlosker diesel engine with a 1500 rpm, 3.72 kw brake power, 110 mm stroke length, 80 mm bore, and 17.5 compression ratio was used. At 1 kg, 2.5 kg, and 4 kg loads and 2B, 3.5B, 5B, and 6B blends, the brake power efficiency, brake thermal efficiency, mechanical efficiency, specific fuel consumption, and emission characteristics were computed and examined. According to our results, the biodiesel outperformed the diesel oil.

Keywords: Biodiesel, Vegetable oil, Esterification, Neem oil, FAME, NOME

INTRODUCTION

Transportation is important in transfer of goods from one place to another. Todays, the world cannot be thought of without transportation. The fossil fuels are the main energy providing medium for transportation. The continuous use of fossil fuels has resulted in the depletion of fossil fuel layers on earth [1,2]. It takes millions of years for the formation of fossil fuels. If we keep using the current ratio of fossil fuel, then there wouldn't be any fossil fuel left for the future generations. Hence, a focus has been laid on alternative fuel all over the world. Different types of fossil-fuel engines are widely employed in industrial power plants, transportation, agriculture, and other applications. The pollution created by these engines has been a major source of concern around the world. They emit smoke, particle pollution, nitrogen oxides (NOx), carbon oxides (CO & CO_2), and unburned hydrocarbons. Biodiesel is an alternative fuel that can be used as a substitute or in combination with diesel in the diesel engines [3,4]. Various branches of research and technology use organic molecules for a wide range of applications [5,6]. Biodiesel, a diesel fuel substitute, has attracted attention worldwide as a blending element or as a direct replacement [7]. Compared to conventional diesel fuels, biodiesel is completely renewable, has reduced exhaust emissions, and can be broken down into smaller components [8]. There are a number of obstacles that must be solved in the rapid

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progress that biofuels have experienced over the past decades. Depending on the economic, social and environmental factors in each region, different types of vegetable oil are chosen to make biodiesel [9]. Various processes, such as micro emulsification, microwave, pyrolysis, and trans-esterification, can be used to make biodiesel from vegetable oils [10]. Among these processes, Trans-esterification is the most commonly used process due to its high efficiency. It is a process of reducing the viscosity of vegetable oils. An alcohol is required for carrying out the trans-esterification process. Methanol is usually used due to its low cost compared to other alcohols. The FAME (Fatty Acid Methyl Ester) produced from this process is then blended with diesel or directly used in engines. This paper focuses on cost-effective production of biodiesel by effectively using the by-products of transesterification process. Any methyl or ethyl esters generated from a tri-glyceride oil molecule are referred to as biodiesel [11]. All plant oils, such as neem, canola, cottonseed, sunflower, safflower, soya bean, corn oil, palm oil, and others are tri-glyceride oils. Used cooking oils as well as fat and tallow can be turned into a biodiesel. Transesterification is a chemical process that cracks the glycerol molecule and replaces it with an alcohol molecule [12,13]. Sodium Hydroxide (Caustic soda) is employed as a catalyst together with an alcohol such as methanol or ethanol.

Vegetable oil-based fuel has a number of advantages over fossil fuels. For instance, it is renewable and offers environmental benefits. It uses the carbon in a cyclic process rather than releasing it into the atmosphere. Plants require sunlight and CO_2 as inputs during their growth cycle, and CO_2 is released during the combustion; the environment provides all of the net energy requirements. As a result, there is a net energy gain. According to a life cycle analysis, there are at least 2.5 units of energy in biodiesel for every one unit of energy used in its manufacturing process. Also, the technology necessary to extract and produce biodiesel is already in place. There are several hundred companies that manufacture oil expellers and related equipment all over the world, as well as numerous companies that specialize in processing technologies. When we use Straight Vegetable Oil (SVO) efficiently in diesel engine, there is requirement in modification of fuel injection system and engine specification to redesign, which is costly. We can overcome these problems by the help of pre-heating, blending and transesterification of vegetable oil. When preheating and blending neem oil, its viscosity can be reduced and the volatility can be increased without affecting its molecular structure. Blending neem oil with diesel further reduces the viscosity, which helps with easy fuel injection. At 35 °C, the viscosity of neem oil is 24.14 cSt and that of diesel oil is 5.96 cSt; this very high viscosity of neem oil leads to problem in spraying and pumping characteristics. In the internal combustion engine, incomplete combustion is due to inefficient mixing of oil with air. Also there is lower volatility problem due to its higher flash point feature. This results in lubricating oil dilution, oil degradation, piston-ring sticking, high carbon deposit formation and injector coking. Cottonseed oils have a high viscosity and low volatility, which results in poor cold starting, misfire and ignition delay. Neem oil is a vegetable oil derived from the fruits and seeds of the neem tree (Azadirachta indica), a tropical tree indigenous to the Indian subcontinent [14]. Figure 1 depicts the neem tree plant that grows on our campus, and Fig. 2 depicts the first stage in extracting oil from neem to make bio-diesel by removing the seed coat and husk through a process known as de-hulling. It is the most important commercially available neem product for organic agriculture and medicine. It's utilized in Ayurvedic, Unani, and folklore traditional medicine to treat a number of diseases. It is also used in cosmetics (soap, hair products, body hygiene creams, and hand lotions). Steroids and a range of triterpeniods,

Fig. 1. Neem plant.

including Azadirachtin, are also found in neem oil. Neem oil is bitter, light to dark brown in color, and has a pungent odor that is said to resemble a mixture of peanut and garlic. It's mostly made up of triglycerides and a lot of triterpenoid chemicals, which give it its bitter flavor. Because it is hydrophobic by nature, it must be emulsified in water for application. It needs to be made with the right surfactants. The characteristics of Neem Oil are listed in the Table 1.

The work focuses on biodiesel generation, which is a reaction in which an ester combines with alcohol to produce another ester and another alcohol. Here, the ester is a triglyceride-containing vegetable oil (Neem oil). Micro Emulsions in diesel fuel, thermal cracking of vegetable oil, and transesterification are all examples for how the neat vegetable oils can be used in diesel engines. Transesterification is the most popular and effective method for using neat vegetable oils out of the four options.

METHODOLOGY

Transesterification is the process by which a fat or oil reacts with an alcohol to create esters and glycerol. Alcohol and triglycerides react to produce glycerol and esters. A catalyst is routinely used to increase the yield and reaction rate. The reaction is reversible, thus more alcohol is needed to shift the equilibrium to the product side. One of the alcohols that may be used in the transesterification process is amyl alcohol, along with methanol, ethanol, propanol, butanol, and others. Alkali-catalyzed transesterification is the method that is most frequently employed in industry since it is much quicker than acid-catalyzed transesterification. Transesterification led to the creation of biodiesel. It is a quick and effective method of making biodiesel. It is conducted with the use of a straightforward experimental setup, as shown in Fig. 3.

As a catalyst, alkali or acid can be used in traditional biodiesel fuel blends. 100 g refined neem oil, 12 g alcohol, and 1 g sodium hydroxide catalyst (NaOH) were used. The experiments used a Soxhlet extraction device. All of these ingredients were combined in a 500 ml flask with a circular bottom. Between 0.5 and 1% of the total weight of the reactor must be filled with catalyst. The above combination was completely mixed and kept at a temperature of 50-55 °C for two hours since a very gradual heat increase was advised. The

Table 1. Properties of Neem Oil

S. No	Properties	Values
1	Densityin (kg m^{-3})	910
2	Specific gravity	0.91
3	Viscosity at 40 °C in cSt	40.75
4	Flash pointin °C	250
5	Heating value in (MJ kg^{-1})	39.82
6	Flash point in °C	65
7	Cetane number	46
8	Cetane number	46

Neem seeds

Neem Kernel

Neem Kernel after drying

Fig. 2. Process of De-hulling

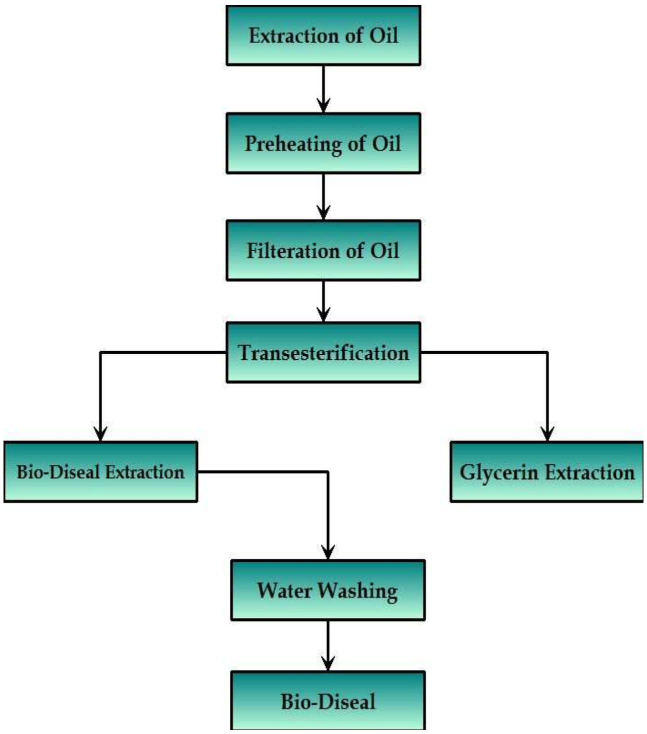


Fig. 3. Proposed methodology.

mixture separates into two distinct layers after 24 h of settling. Neem oil's methanol extract, or fatty acid methyl ester, or biodiesel, were present first, followed by glycerin. The glycerin and water were separated using a conical separating funnel. After washing with warm water, glycerol, catalyst (NaOH), and methanol were separated to provide FAME (fatty acid methyl ester). The excess water and methanol from distillation were taken out.

Phosphoric acid was used to neutralize the catalyst, which included NaOH, Glycerol, methanol, and water. Finally, glycerin was obtained as a by-product of alkali transesterification. R1, R2, R3, and R' stand for different alkyl groups. The transesterification process causes a significant shift in the viscosity of vegetable oil. This procedure produces biodiesel that is completely miscible with mineral diesel in any proportion. Figure 4 depicts the steps involved in making biodiesel, and Fig. 5 depicts the neem biodiesel produced using this method and the properties of biodiesel and engine specification are shown in Tables 2 and 3.

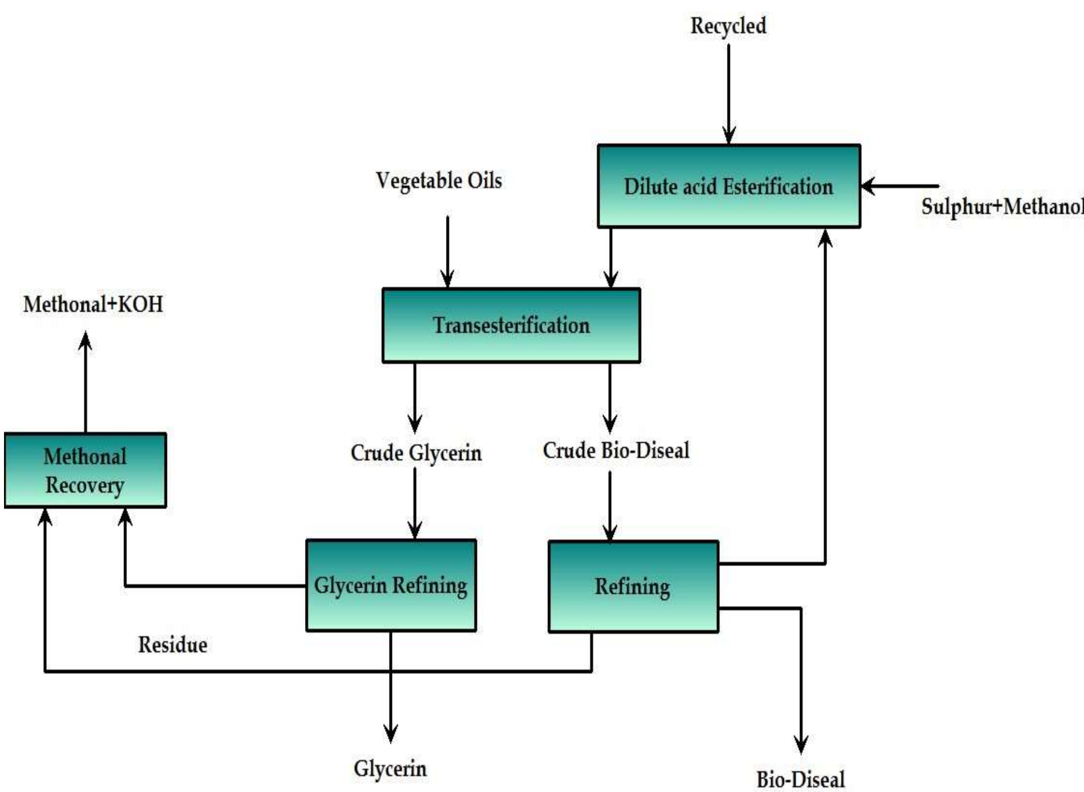
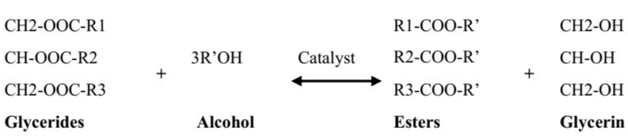


Fig. 4. Process flow chart.

Fig. 5. Neem biodiesel.

Table 2. Properties of Neem Biodiesel

Properties	Values
Density	810 kg m^{-3}
Specific gravity	0.81
Calorific value	39.4 MJ kg^{-1}
Flash point	65 °C
Fire point	75 °C
Cetane number	46



A Single cylinder 4 stroke kirlosker diesel engine, 1500 rpm, 3.72 kw brake power, 110 mm stroke lengthand, 80mm bore with 17.5 compression ratio were employed for this experimental work. The gas analyzer was used to measure the concentrations of nitrogen oxides (NOx), unburned hydrocarbons (UHC), and carbon monoxide in gaseous emissions (CO). This method was also used to determine the brake thermal efficiency and brake specific fuel, which were compared to standard fuel.

RESULT AND DISCUSSION

The engine was run at various speeds ranging from 500 to 1500 rpm to investigate the influence of brake thermal efficiency. When the engine speed increased to 1050 rpm, the brake thermal efficiency and fuel consumption both were improved. Even with increasing the fuel usage, there was a minor decline in Brake thermal efficiency beyond 1050 rpm, due to increase mechanical friction. This is a sign of a low calorific value combined with increased fuel consumption. There was a high Brake thermal efficiency at 1050 rpm, indicating complete fuel combustion; thus, more research was done at this rpm.

Brake Power Efficiency

The brake power efficiency was calculated at 1 kg, 2.5 kg and 4 kg loads and 2B, 3.5B, 5B and 6B blends. The calculated values were plotted in Fig. 6. The brake power efficiency increased as the load increased. Content of the biodiesel in the blend hikes and the brake power also increased. It is also observed that Brake power efficiency

Table 3. Engine Specification

Engine type	KIRLOSKAR single cylinder 4 stroke engine
RPM	1500
Type	1 Cylinder 4Stroke
Brake power	3.72 kw
Bore	80 mm
Stroke length	110 mm
Method of starting	Manual
Cooling system	Water
Compression ratio	17.5
Rotation	Clockwise/Anticlockwise
Fuel filler	Present

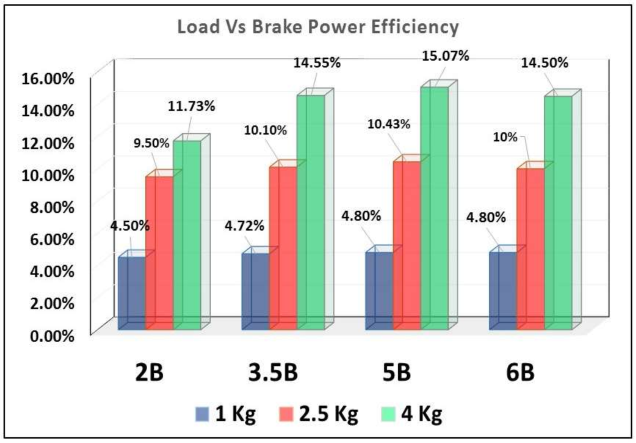


Fig. 6. Load *vs*. brake power efficiency.

increased with an increase in the percentage of biodiesel in the blend from 2B to 3.5B. BPE had maximum value for 5B blend. The reason for the increase in BPE is the presence of more oxygen in biodiesel blend compared to that in pure diesel. With further increase in percentage of biodiesel in the blend, a slight decrease in BPE was obtained. The reason for the decrease in the BPE may be due to less volatility of thebiodiesel as compared to the pure diesel.

Brake Thermal Efficiency

The thermal efficiency of the brake was also computed at various loads and mixes, and the outcomes are shown in Table 5 and illustrated in Fig. 7. When the biodiesel content was raised, the thermal efficiency of the brakes increased. However, the 2B blend's thermal efficiency decreased as the load increased. For other blends, the load and thermal efficiency were precisely related.

Mechanical Efficiency

The mechanical efficiency was determined and shown in Fig. 8, and values at various loads and mixes are shown in Table 6. The mechanical efficiency diminished as the biodiesel concentration rose. However, when the load increased, a blend's mechanical efficiency increased. For various mixes and loads, the precise fuel consumption was calculated; the results are shown in Table 7 and Fig. 9 respectively. According to results, it was found that specific fuel usage decreased as the load increased.

Table 4. Brake Power Efficiency

BLENDS	1 Kg	2.5 Kg	4 Kg
2B	4.5%	9.5%	11.73%
3.5B	4.72%	10.10%	14.55%
5B	4.8%	10.43%	15.07%
6B	4.8%	10%	14.5%

Table 5. Brake Thermal Efficiency

BLEND	1 Kg	2.5 Kg	4 Kg
2B	30.86%	30.55%	28.76%
3.5B	49.73%	48.58%	49.21%
5B	43%	43.2%	44%
6B	65%	60%	59%

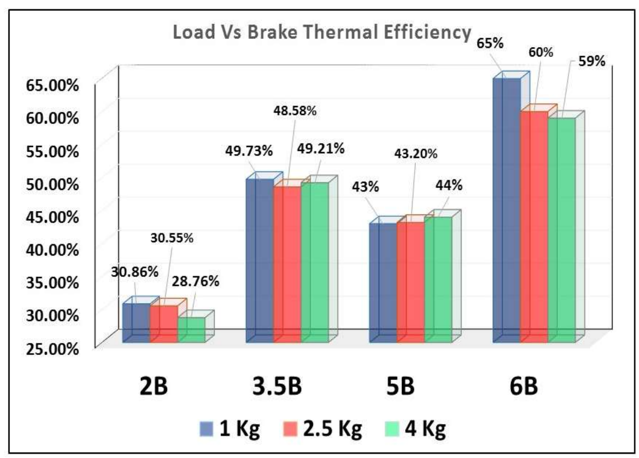


Fig. 7. Load *vs*. brake thermal efficiency.

Fuel Consumption

Neem oil methyl ester and various other biodiesel blends were tested for their carbon monoxide emissions at varied brake mean effective pressures and rated engine speeds of 1050 rpm (BMEP). When using biodiesel blends at all BMEP values instead of diesel, the engine produced greater CO.

Carbon monoxide emissions can be reduced by up to 15% by adding more NOME (Neem Oil Methyl Ester) to diesel

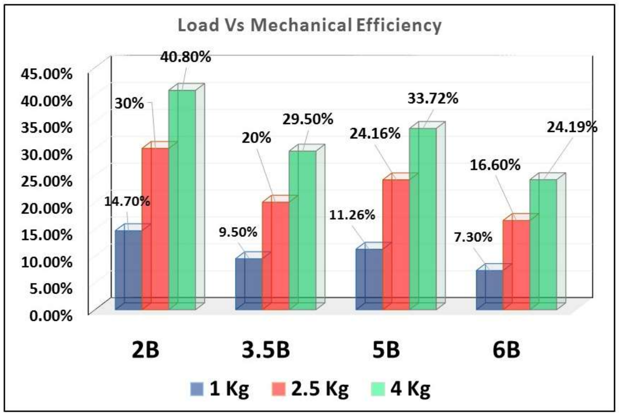


Fig. 8. Load *vs*. mechanical efficiency.

Table 6. Mechanical Efficiency

-BLEND	1 Kg	2.5 Kg	4 Kg
2B	14.7%	30%	40.8%
3.5B	9.50%	20%	29.5%
5B	11.26%	24.16%	33.72%
6B	7.3%	16.6%	24.19%

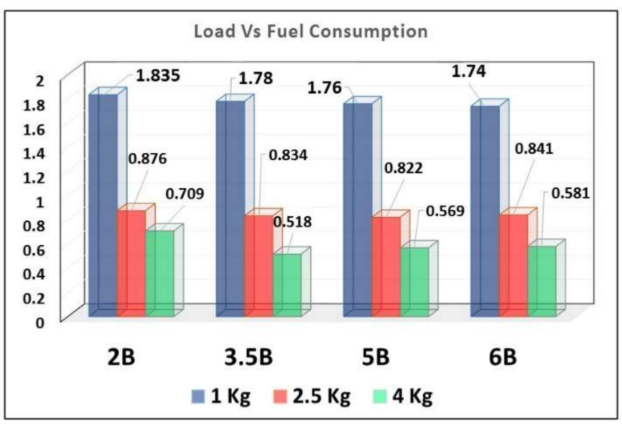


Fig. 9. Load *vs*. Specific fuel consumption.

Table 7. Specific Fuel Consumption

BLEND	1 Kg	2.5 Kg	4 Kg
2B	1.835	0.876	0.709
3.5B	1.78	0.834	0.518
5B	1.76	0.822	0.569
6B	1.74	0.841	0.581

fuel, but they can be also increased by more than 15%, with 11.15 percent or so of the oxygen in biodiesel. This makes the complete fuel combustion possible. According results, biodiesel can cut total load and speed ranges by up to 51.6%, while also reducing the carbon emissions.

Emission

We studied the NOx emission characteristics of different BMEPs at different neem oil mixes. The findings showed that while blended neem oil emitted higher NOx, diesel fuel emitted less gas. The use of Neem oil resulted in a 5% increase in NOx emissions as compared to regular gasoline.

The oxygen in NOME contributes to the generation of more NOx. The findings of the corresponding emission are shown in Table 8 and Fig. 10. The filter smoke number was investigated in connection to varying BMEP for different gasoline blends. The results demonstrate that NOME had a lower filter smoke number for biodiesel blends than that for diesel fuel.

Table 8. Emission Table

BLEND	O2	CO	NO_X
DIESEL	7.2	0.0045	1.16
2B	10.5	0.0006	1.20
3.5B	10.3	0.0013	1.36
5B	9.3	0.0017	1.49
6B	8.6	0.0022	1.57

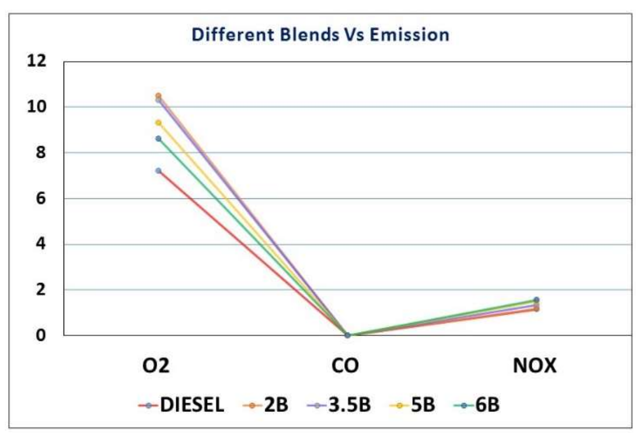


Fig. 10. Emission for different blend.

CONCLUSION

Natural fuels like biodiesel are more reliable energy sources. The manufacturing of the biodiesel fuel has improved significantly in order to address the initial viscosity issues. As a non-toxic, biodegradable alternative to fossil fuels that is made from a variety of renewable resources, biodiesel is becoming more and more popular. Neem tree oil has the potential to be used as a renewable energy source. Neem oil output needs to be increased significantly, requiring a huge resource commitment. Neem oil, a novel biodiesel feedstock that is naturally renewable, has been the subject of many studies. Investigations have been conducted on the performance and exhaust emissions of biodiesel, incorporating neem oil. Here, we observed that by using the 2B blend the brake power efficiency was improved. As the biodiesel content rose, brake thermal efficiency rose too. When the biodiesel content dropped, the mechanical efficiency rose. The efficiency for 2B was estimated to be 14% for the minimum load. However, when the load increased, the particular fuel consumption reduced. The diesel-NOME blends increased the NO_X emissions while decreased the smoke and CO emissions. The decrease in the CO and smoke emissions as well as the increase in the NO_X emissions in diesel-NOME blends may be related to the fuel's oxygen content. Blends with more than 15% NOME-diesel contents were atomized poorly and only partially burned in the engine. So, the quantity of the engine exhaust emissions increased. Future usage of this oil's ester as a green substitute fuel for diesel engines can lead to cleaner environments.

NOMENCLATURE

NO_X: Oxides of Nitrogen
CO: Carbon Monoxide
CO_2: Carbon di Oxide
FAME: Fatty Acid Ethyl Ester
SVO: Straight Vegetable Oil
UHC: Unburned Hydrocarbon
NOME: Neem Oil Methyl Ester

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