Production of Biodiesel from Water Hyacinth weed and testing of its blends on CI engine

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Abstract

This research endeavors to explore the feasibility of biofuel production from water hyacinth. Crude water hyacinth oil (WHO) is extracted using the Soxhlet technique and then converted into the biodiesel through transesterification process. Additionally, the research involves blending WHO biodiesel with fossil diesel (FD) to make four blends: B10 (10% biodiesel, 90% diesel), B20 (20% biodiesel, 80% diesel), B25 (25% biodiesel, 75% diesel), and B30 (30% biodiesel, 70% diesel), each consisting of 100 ml (vol.). Performance evaluation was conducted using a 4-stroke, single cylinder, water-cooled CI engine. Analysis of emissions, including NO_X, CO, CO_2, and HC emissions, reveals that HC and CO emissions of biodiesel blends emit fewer pollutants compared to fossil diesel but NO_X, and CO_2 of biodiesel blends are more than fossil diesel. Furthermore, the levels of harmful pollutants emitted from the biodiesel blends are substantially lower than those from conventional diesel fuel. Brake Specific Fuel Consumption (BSFC) and Brake Thermal Efficiency (BTE) of these blends are also calculated and compared with diesel fuel. By transforming a prevalent environmental challenge into valuable resources for energy and fuel production, this research promotes sustainable and environmentally friendly approaches to invasive species management and renewable energy generation.

Keywords: *Crude water hyacinth oil; Soxhlet Extraction; Transesterification; Water hyacinth biodiesel; Performance and Emissions analysis*

Nomenclature

BD	:	Biodiesel	HC	:	Hydrocarbon
DE	:	Diesel Engine	BSFC	:	Brake Specific Fuel Consumption
WHO	:	Water hyacinth oil	BTE	:	Brake Thermal Efficiency
NO_X	:	Nitrogen Oxide	B10	:	10ml WHO + 90ml FD
CO	:	Carbon Monoxide	B20	:	20ml WHO + 80ml FD
CO_2	:	Carbon dioxide	B25	:	25ml WHO + 75ml FD

FD	:	Fossil Diesel	B30	:	30ml WHO + 70ml FD

1. Introduction

During the past decades, energy has played an important role in conventional and Economic aspects throughout various nations. The rapid decline in the availability of fossil fuels and the increasing impact of global warming on our planet are driving the evaluation and exploration of alternative fuels [1]. The energy requirements of the world have predominantly been met through the utilization of fossil fuels such as natural gas, coal, and petroleum products. The transportation sector is predominantly characterized by the prevalence of diesel engines, attributed to their superior thermal efficiency and substantial hauling capacity [2]. The significant demand and utilization of fossil fuels have led to heightened emissions, prompting a search for sustainable alternative substrates for existing diesel engines. The choice of the best alternative fuel is crucial in terms of fuel consumption, performance, and pollution. Among different alternative fuels, biodiesel is the most promising option for internal combustion engines [3]. The intrinsic benefits of biodiesel, including improved lubricity, non-toxicity, biodegradability, a higher cetane number, increased oxygen content, and diminished transportation risks, indicate its viability as an alternative for conventional unmodified diesel engines. The biomass derived from water hyacinth has been identified as a viable source for biodiesel production. The primary constituents of water hyacinth biomass include hemicellulose at 48%, cellulose at 18%, and lignin at 3.5%. India, heavily reliant on costly oil imports to meet its energy demands, is exploring biodiesel as a viable solution [4]. The government has already approved a 5% biodiesel blend with diesel and is considering increasing the blending ratio to 20% soon, aiming to save significant costs and enhance energy security. There are lots of researchers who have been doing research in the types of bio-oil to convert it into biodiesel to check its effect on the diesel engines such as Mishra et al. 2023 [5] explored microalgae oil as a sustainable diesel replacement. Their experiments with different blends in diesel engines showed promise for reducing emissions and improving energy security. Saini et al. 2023 [6] provided a thorough examination of corn oil BD and its suitability for use in DE. By analyzing its performance and emissions characteristics, the study underscores the potential of corn oil biodiesel as a sustainable alternative to traditional diesel. Ahmad and Saini 2022 [7] examined the performance and emission analysis of DE in ternary combinations of mango seed BD and diesel to determine the effect of butanol additives.

The study's findings contribute to the ongoing discourse on sustainable energy solutions, particularly in the context of alternative fuel formulations for transportation applications. Kumar et al. 2023 [7] conducts experimental analysis on the performance and emission characteristics of diesel engines using blends of lemongrass biodiesel and TiO_2 nano additives. By examining the effects of TiO_2 nanoparticles on combustion processes, the study contributes to advancing the understanding of nano-enhanced biofuels in the context of sustainable energy solutions. Kumar et al. 2023 [9] examine the impact of synthesized lemongrass BD on the performance and emission analysis of compression ignition (CI) engines.

By analyzing engine performance and emissions, the research contributes to the growing body of literature on sustainable energy solutions, offering insights into the potential of biodiesel derived from lemongrass as an alternative to conventional diesel. Kumar et al. 2024 [8] examined the influence of n-pentanol in novel ternary blends of water hyacinth biodiesel and diesel on diesel engine performance and emissions. Their study contributes insights into enhancing engine efficiency and reducing emissions through alternative fuel formulations. Alagu et al. 2019 [9] investigated the viability of novel water hyacinth biodiesel as an alternative fuel for unmodified diesel engines.

Regardless of the augmenting engrossment in biodiesel usage as a sustainable substitute for conventional non-renewable fuels, there persists a notable lack of research regarding the utilization of water hyacinth weed for biodiesel production. Most contemporary research has addressed conventional organic feedstocks like vegetable oil, animal fat, or Jatropha seeds, etc., omitting the proficiency of invasive aquatic weeds like water hyacinth. This weed is not only sample in terms of amount and catastrophic for the aquatic biosphere, but it also serves as an unexploited resource for biofuel production due to its high lignin and hemicellulose content.

The proposed investigation into the utilization of water hyacinth oil as biodiesel represents a significant advancement in the field. The purpose of this study is to use a Soxhlet apparatus to extract oil from water hyacinth weed and then use a transesterification procedure to turn it into BD.

Subsequently, the prepared biodiesel was mixed with fossil diesel to evaluate its effects on a 4S single-cylinder diesel engine, focusing on performance parameters and emission characteristics.

2. Materials and Methods

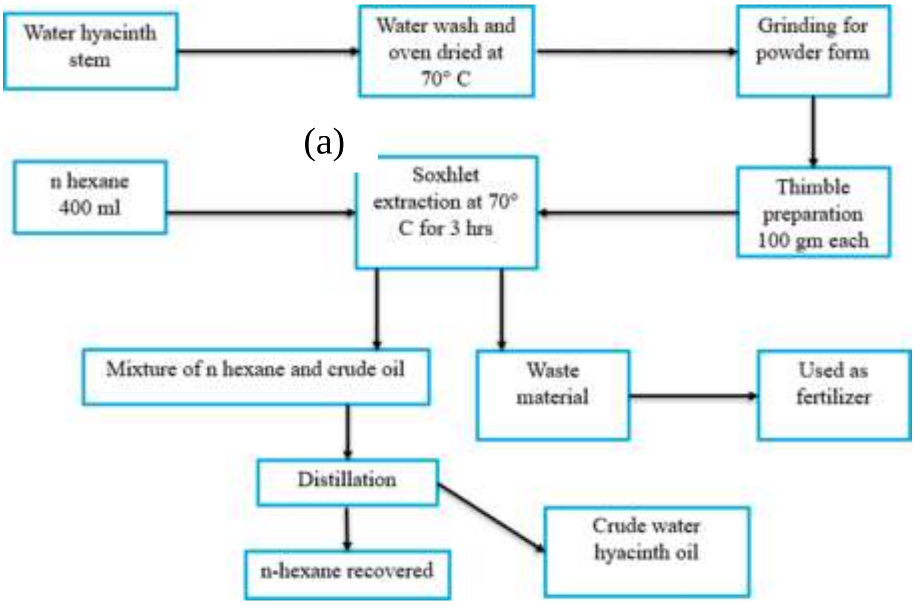
2.1. Materials

Chemical such as n-hexane, methanol, sodium hydroxide are procured from eastern scientific emporium Gorakhpur, U.P., India. Fossil diesel for blending was purchased from Indian Oil Corporation Limited (IOCL), Gorakhpur, UP, India.

2.2. Methods

2.2.1. Oil Extraction and Biodiesel Production

Water hyacinth oil is extracted via the soxhlet extraction technique from dried water hyacinth powder. Harvesting of water hyacinth weed followed by water washing to remove impurities. Further, drying of green water hyacinth is done in sunlight for about 4 weeks preceded by oven drying at 70 ℃. It was found that 3.5 kg of green water hyacinth plants were converted into 1 kg after drying. The dried plants are chopped into small pieces of size < 5 mm and crushed into powder form using a grinder. Total 2.5 kg of dried powder was obtained after drying and shredding from 10 kg of water hyacinth plant. For the oil extraction, 100 gm dried powder of water hyacinth was taken in a thimble and kept in the soxhlet chamber, three-fourths of the conical flask is filled with n-hexane and kept on a heating mantle. The condenser is connected to the top of the extractor, with the intake and outlet pipes of the condenser corresponding to a pipe through which cold water enters, and hot water departs, respectively. The heating mantle of the Soxhlet apparatus turns on and the temperature reaches 69 ℃, the boiling point of n-Hexane. Thereafter, n-hexane begins to boil and transforms into vapor, which is sent into a condenser via a vapor tube, where it reverts to liquid formThe liquid form is then passed through a thimble after a fixed label. It returns along with extracted water hyacinth oil (WHO) into a conical flask via a siphon tube. The extracted WHO is not vaporized with n-hexane because it has a high boiling point. The same procedure as discussed above, is repeated 4-5 times for the complete extraction of oil from water hyacinth biomass and it takes approximately 2.5 hours for each thimble. The same process is done for all 25 thimbles (100 gm each) of samples. This results in a mixture of WHO and n-hexane in a conical flask. The process for the extraction of oil through soxhlet apparatus is shown in Figure 1(a) and (b)



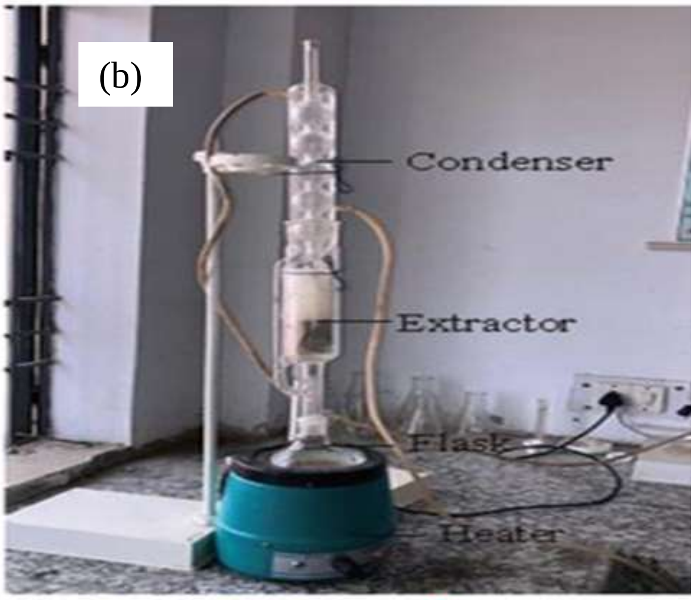
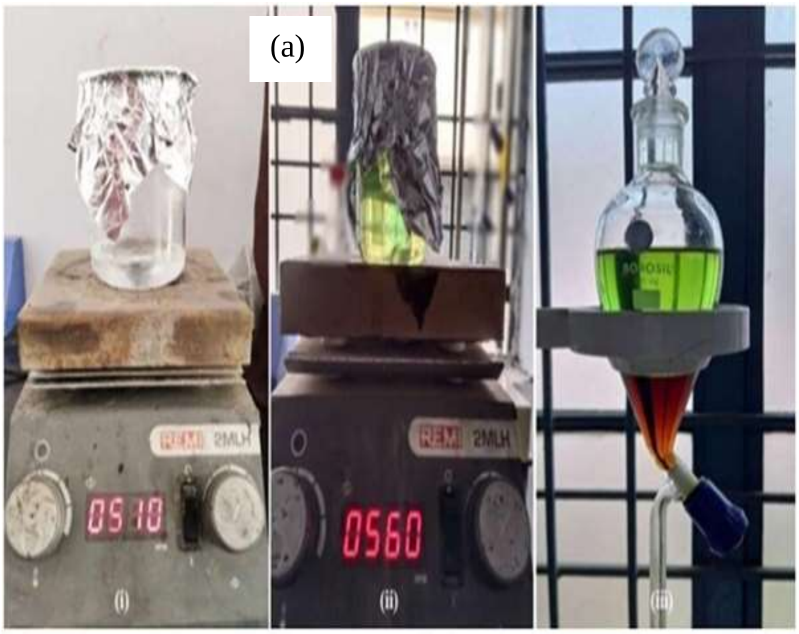


Figure 1 Process for the extraction of oil from water hyacinth (a) Flow diagram for extraction of oil (b) Soxhlet apparatus for oil extraction

Flask mixture (WHO and n-hexane) heating is done at a temperature of 69 ℃ (boiling point of n-hexane) and the flask relates to a horizontal condenser which has an inlet and outlet for cold water supply and hot water exit. This way n-hexane starts boiling and evaporates from the mixture which condenses in the condenser and is collected in another flask. Figure 2 shows the setup for the separation of oil with n-hexane through distillation unit.

Figure 2. Setup for separation of crude water hyacinth oil with n-Hexane

KOH of 1% by weight mixed with 20 ml methanol in a magnetic stirrer until it dissolved completely. Meanwhile 100 ml of crude WHO is heated in a flask at ±60 ℃ by heating mantel to reduce its viscosity and remove oil moisture. During the process temperature should not exceed the boiling point of methanol otherwise it may evaporate. After that the prepared mixture of KOH and methanol is mixed with heated WHO and finally the solution is stirred at 500-600 rpm for 150 minutes approximately. During the process heat may be released, hence, a condenser is placed vertically over the flask and closed from another side. After that the stirred solution is kept in the separating funnel for 24 hours. In this way glycerin (used in beauty products and medical applications) is settled down and WHB is above the glycerin surface, which is further separated. WHB (50ml) is then washed with lukewarm water and dried at 100°C for about 20 minutes. These steps are repeated for 5 samples of 100 ml each. 250 ml of WHB is obtained after transesterification. Figure 3 shows the process of producing biodiesel. After the preparation of biodiesel, the important properties such as Density, Kinematic Viscosity, Flash Point, Calorific value, Cetane Number, Water Content, Carbon Residue, are calculated and compared with fossil diesel which are shown in Table1.



(a)

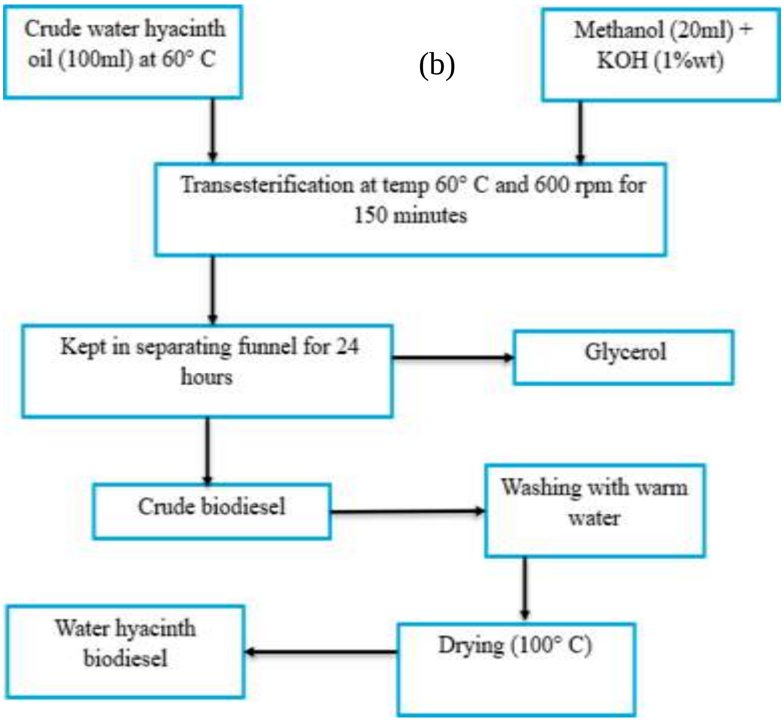


Figure 3. Process to produce biodiesel (a) Setup for the biodiesel production (b) Flow diagram for the production process of water hyacinth oil biodiesel

Table 1. Properties of Biodiesel and Fossil Diesel

Fuel Properties	**WH Biodiesel (B100)**	**Fossil Diesel**
Density (kg/m^3)	887	838
Kinematic Viscosity (mm^2/s)	3.96	2.76
Flash Point (°C)	212	68
Calorific value (MJ/kg)	36.9	42.7
Cetane Number	52.5	48
Water Content (%)	0.04	0.02
Carbon Residue (%)	0.21	0.16

2.2.2. Preparation of Blending mixtures

After the preparation of biodiesel four blends of biodiesel and fossil diesel were prepared and named B10 (10ml WHO + 90ml FD), B20 (20ml WHO + 80ml FD), B25 (25ml WHO + 75ml FD) and B30 (30ml WHO + 70ml FD) with the help of using magnetic stirrer. The mixture was stirred at 800 RPM for 30 minutes and room temperature of around 25 °C. Figure 4 shows the image of prepared blending mixtures.

Figure 4. WHO biodiesel blends mixture

3. Results and Discussions

In this section the BM of BD and FD blends are used as fuel for the performance and emissions characteristics of 4 S single cylinder DE.

The prepared BM was run in a 4-S, single-cylinder vertical-cooled self-governed diesel engine (DE) with a rope brake dynamometer. The outcomes were compared to the engine performance based on FD. Figure 5 shows the schematic and experimental setup of diesel engines. With a varied load ranging from 0 to 5 kg, experiments were conducted at a constant DE speed of 1500 rpm. Rope brakes equipped with loading screws and spring balances allowed for the variation of loads. The amount of time it took to use 10 milliliters (burette) of gasoline at varying load was noted for engine loads ranging from 0 to 5 kg. Throughout the experiment, a digital multichannel temperature indicator was used to check the EGT, and a gas analyzer was used to determine the exhaust gas composition. The average value was provided after each experiment was conducted in triplets. For FD and various BM, the engine performance parameters such as BSFC and BTE are computed using a standard equation. DE performance is computed as follows in terms of BTE and BSFC: [10]

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$$BSFC\left(\frac{kg}{kWh}\right) = \frac{Fuel\ Consumption\ Rate}{Brake\ Horse\ Power} \times 3600 \quad (1)$$

$$BTE(\ \%\ ) = \frac{Brake\ Horse\ Power(\ kW)}{Fuel\ Consumption\ Rate \times Calorific\ Value} \times 100 \quad (2)$$

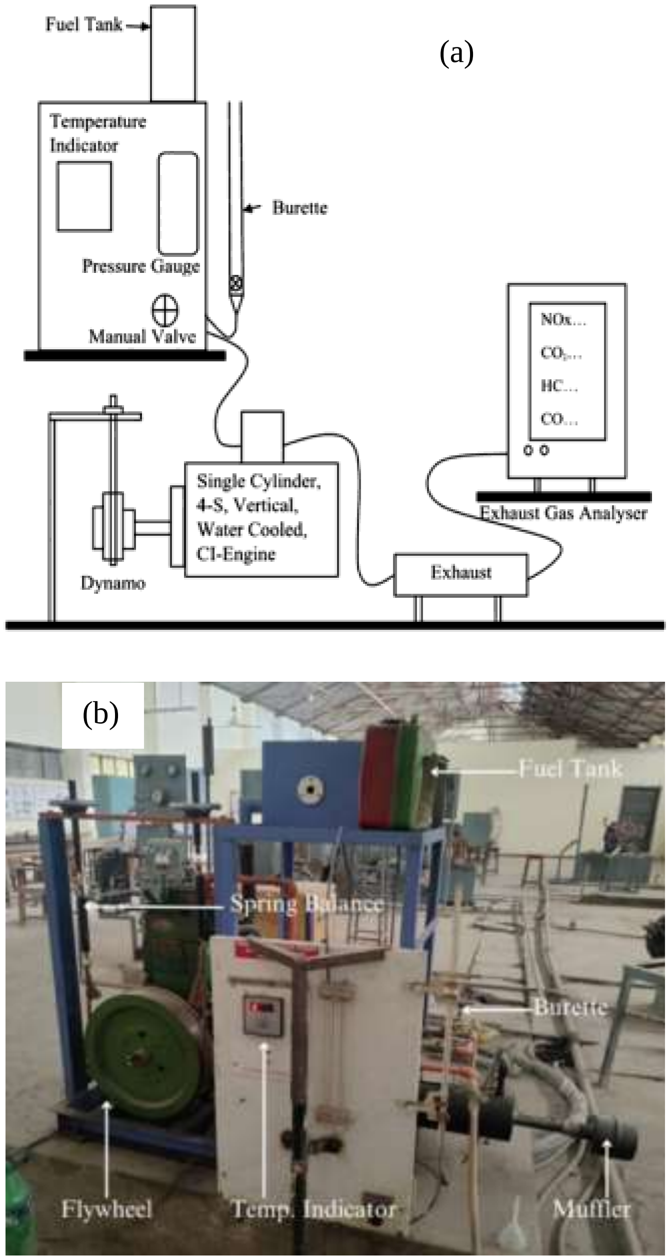

Figure 5 (a) Schematic diagram (b) Real image of diesel engine

3.1. Engine performance and emission analysis

3.1.1. Effect of varying load on BSFC

BSFC refers to the quantity of fuel required to produce per unit of power and should be lower for efficient fuel. Figure 6 shows the variation of BSFC with load for fossil diesel and different blending mixtures. Numerous fuel properties, including density, heating value, viscosity, and cetane number, have a big impact on the BSFC. BSFC decreases as engine load increases for all the blends. This means that the engines are more efficient at higher loads. The diesel fuel has the lowest BSFC at all loads, followed by B20, B30, B25, and B10. This means that diesel fuel is the most efficient and consumes less fuel at same load, followed by the BD blends with higher percentages of biodiesel.

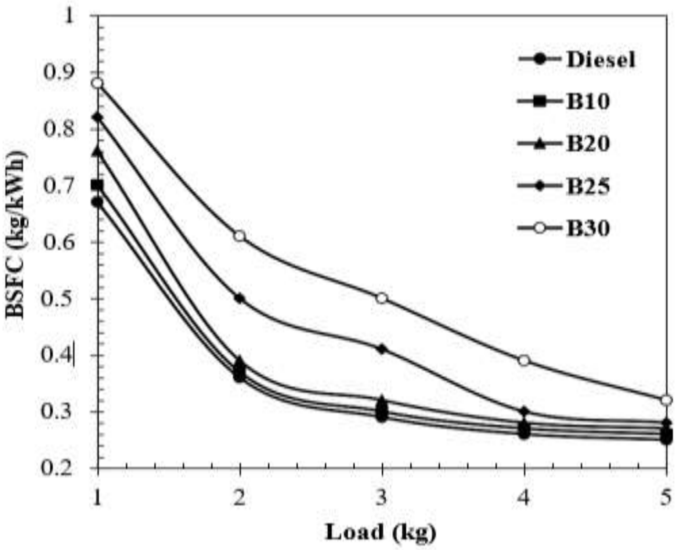

Figure 6. BSFC versus engine load

3.1.2. Effect of varying load on BTE

BTE refers to the combustion of fuel within a combustion chamber and transforms it into desired work. The BTE with variation of load is shown in Figure 7. BTE depends on the calorific value and available oxygen contents (proper burning) of the individual fuel. A higher calorific value reduces the BSFC resulting in higher BTE. The BTE increases as engine load increases for all the fuels. This means that the engines are more efficient at higher loads. The Diesel fuel has the highest BTE of all loads, followed by B10, B20, B25, and B30. This means that the diesel fuel is the most efficient, followed by the biodiesel blends with higher percentages of biodiesel.

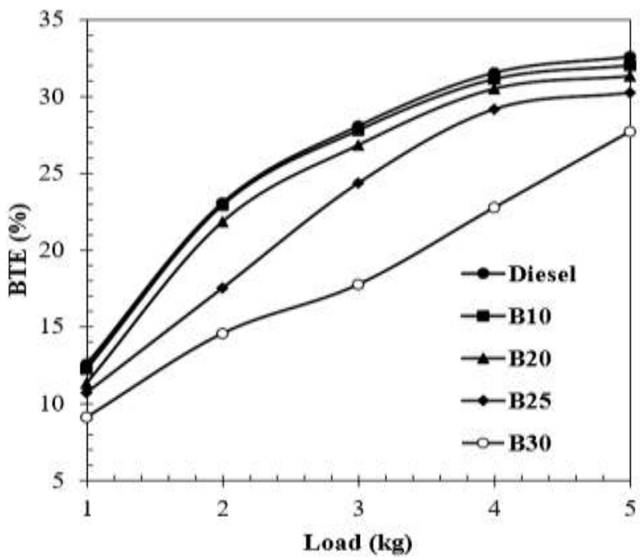

Figure 7 BTE versus engine load

3.1.3. Effect of varying load on HC

The HC with variation of load is shown in Figure 8. HC emission shows incomplete fuel/air combustion in the cylinder of the engine. HC emission indicates the quality of combustion that is lower than the HC emission results in better combustion. The presence of oxygen in biodiesel in WHB mixtures results in reduced HC emissions as the engine load varies, thereby enhancing combustion efficiency. Because of the excess fuel burned in the combustion chamber, HC emissions rise as engine load increases.

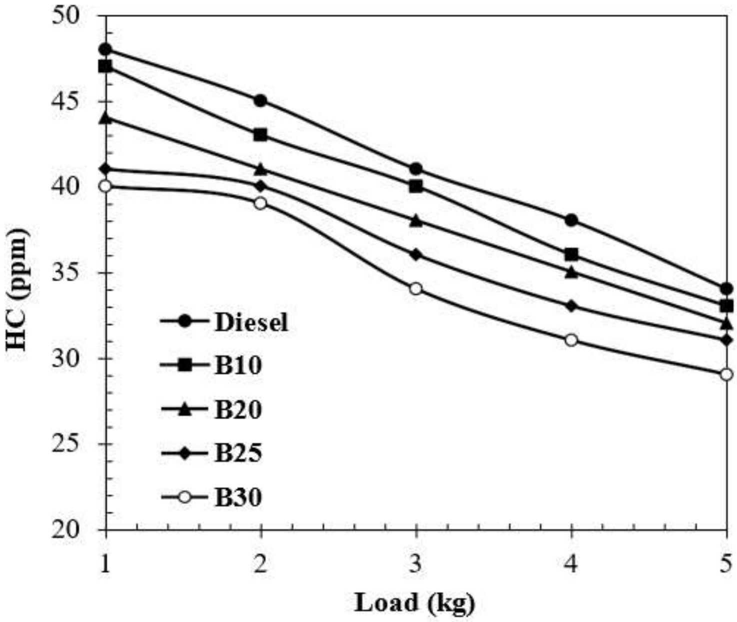

Figure 8 HC emission versus engine load

3.1.4. Effect of varying load on NOx

The NO_x with variation of load is shown in Figure 9. The formation of NO_x is highly dependent on combustion temperature, pressure, and the availability of oxygen and nitrogen. Various factors may be responsible for the formation of NO_x such as important fuel properties, operating conditions, reaction time, combustion temperature and engine design. It is assessed that, as engine loads for biodiesel blends rise, NO_x emissions correspondingly increase due to the heightened combustion rate, availability of O_2, and the net heat released in preceding combustion cycles. As biodiesel concentration rises, NO_x emissions rise linearly.

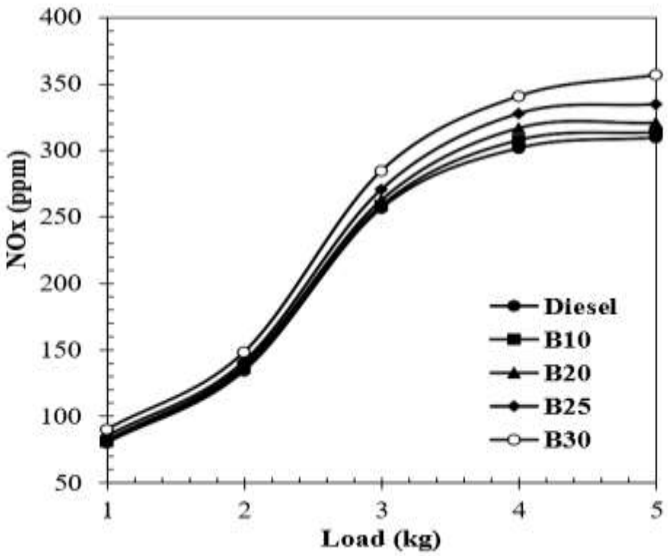

Figure 9 NO_x emission versus engine load

3.1.5. Effect of varying load on CO_2

The CO_2 with variation of load is shown in Figure 10. The thorough burning of fuel mixes emits more CO_2 owing to their oxygen content, hence indicating the excess availability of oxygen. The increased levels of CO_2 emissions indicate improved fuel oxidation due to the correlation between CO and CO_2 emissions. WHB blends have elevated CO_2 emissions across different engine loads, which may be attributed to the oxygen concentration that promotes full combustion.

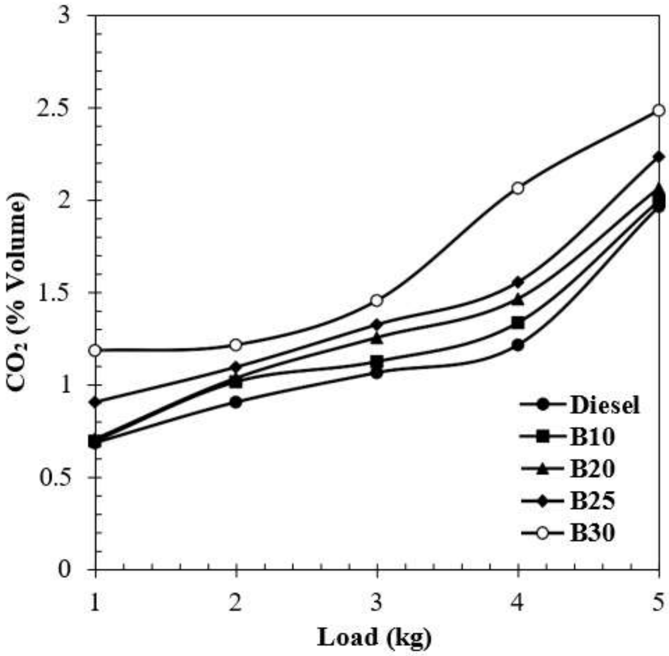

Figure 10 CO_2 emission versus engine load

3.1.6. Effect of varying load on CO

The variation of load with CO is shown in Figure 11. Diesel engines typically produce lower CO emissions because they operate more efficiently with a leaner mixture. The oxygen concentration, burning rate, fuel spray characteristics, in-cylinder temperature, and ignition centers-all of which are crucial in the formation of CO-vary depending on the use of biodiesel. It is found that WHB blends, which have an inherent fuel O_2 component, have a lower CO than diesel fuel since diesel fuel lacks O_2. Increasing engine loads reduces CO emissions because more fuel participates in combustion, resulting in the formation of more fuel-rich zones with sufficient O_2.

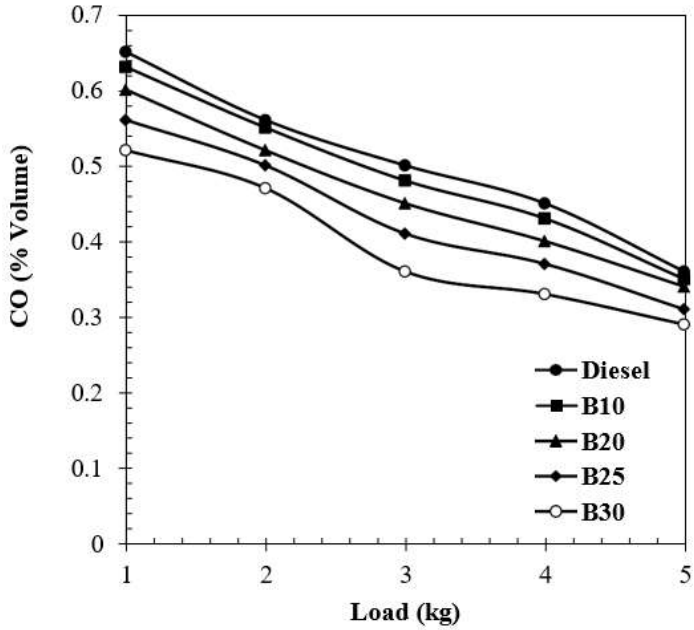

Figure 11 CO emission versus engine load

4. Conclusions

Based on the results of performance and emissions characteristics of diesel engine using the blends of fossil diesel and biodiesel were done and the following conclusions were obtained such as performance in terms of BSFC and BTE, it was seen that the fossil diesel have less BSFC in comparison to blends and it increases by increasing the blends in biodiesel. Similar trends were also observed during the case of BTE that diesel has the highest BTE in comparison to biodiesel blends and BTE decreases by increasing the blends in fossil diesel. Emissions such as HC, NO_x, CO_2, and CO were obtained based on the results. It was determined that diesel has the greatest emissions of HC and CO when compared to blends of BD and FD, while diesel has the lowest emissions of NOx and CO_2 when compared to blends of BD.Overall, Biodiesel blends can be an environmentally friendly alternative due to lower CO and HC emissions, but their impact on fuel efficiency and NO_x emissions
Should be considered.

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