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Performance and emission characteristics of diesel engine with hemp biodiesel blends

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Abstract: The increased population in the world has resulted in excessive use of conventional fossil fuel resources especially petroleum diesel over the world wide which in turn made every nation to find out the possible alternate energy sources for replacement of petroleum diesel. This article investigates the suitability of hemp biodiesel blends generated from hemp vegetable oil can be used as a fuel a single-cylinder, four-stroke diesel engine. The conventional transesterification procedure is used to transform hemp vegetable oil to hemp biodiesel. The fuel qualities of biodiesel and its blends have been analyzed and determined to be equivalent to those of petroleum diesel, in accordance with the criteria set by ASTM. The purpose of this work was to examine the performance and emission characteristics of a diesel engine employing hemp biodiesel blends and compare them with those corresponding to conventional diesel fuel which was employed as a reference fuel. The results showed that as the load on the diesel engine increased, the brake specific fuel consumption (BSFC) decreases, however the brake thermal efficacy (BTE) as well as exhaust gas temperatures (EGT) increased for the blends of hemp biodiesel. In the emission test, as load increases, there is an increase in the emissions of CO_2, UBHC and NO_X but decreases in CO. Additionally, the emission of smoke exhibits an inverse relationship with load, increasing at lower loads as well as decreasing at higher loads. Hemp biodiesel blends provide diesel engine efficiency and emission characteristics that are comparable to those produced by diesel engine utilizing standard diesel fuel.

Nomenclature

ASTM	American Society for Testing and Material	HC	hydrocarbons
CO	carbon monoxide	NO_X	nitrogen oxides
BP	brake power	ppm	parts per million
CO_2	carbon dioxide	BTE	brake thermal efficacy
UBHC	un burnt hydrocarbons	η_{mech}	mechanical efficacy
EGT	exhaust gas temperature	BSFC	brake specific fuel consumption

1. Introduction

As a consequence, there is a perpetual rise in the worldwide need for energy. Global energy consumption is expected to increase by a factor of fifty between 2005 and 2030, as reported by the International Energy Outlook'2008. In the current scenario, the International Energy Outlook '2030, estimates that fossil fuels will continue to have a dominant position on the global energy market, accounting for between 26 and 27% of total energy consumption [1]. Since the commencement of the industrial age in the 19th and 20th centuries, energy has been a crucial factor in ensuring that humans may continue to enjoy a comfortable standard of life and achieve economic prosperity [2]. It has become the most important need for the human existence. Highly increased consumption of fossil fuels and also using these energy sources has lead an environmental impact [3]. According to the findings of a study conducted by the International Energies Agency (IEA), it is anticipated that the demand for energy on a worldwide scale would rise by an additional fifty percent by the year 2030 in comparison to the current level. The report further highlights that China and India are expected to account for around 45 percent of this increase in energy demand. The transportation sector has grown steadily over the past 30 years due to more number of vehicles worldwide. From 2005 to 2035, it is predicted that the energy consumed by worldwide transportation will rise by an average of 1.8% annually [2]. According to the International Energy Statistics database maintained by U.S. Energy Information Administration (EIA), the annual growth rate of global energy consumption is 1.6%, encouraging the search for alternative fuel sources that can replace traditional fossil fuels [1]. Diesel is widely used in transportation, commercial, agriculture, industrial and domestic sectors to generate mechanical energy and electricity. When compared to mineral diesel, the alternative fuel known as biodiesel, which is produced from vegetable oils as well as animal fats, shows tremendous promise as being extremely kind to the environment [3]. The transportation industry has the position of being the second most significant user of energy globally, contributing to around 30% of the total energy provided worldwide. Notably, a substantial 80% of this energy is allocated for road transportation purposes. Currently, the transportation industry is widely acknowledged as the primary contributor, accounting for over 60% of global oil consumption. Furthermore, it is anticipated to exhibit the most rapid growth in energy demand among other sectors in the foreseeable future. In the transportation sector, the overwhelming majority of fossil fuel use, around 97.6%, is derived from oil, while a smaller fraction, accounting for 20%, is sourced from natural gas [2]. Diesel engines have maintained a dominant position in the automotive industry since its introduction by Rudolf Diesel in 1910. its popularity stems from their notable attributes, including great thermal efficiency, sturdy construction, and long-lasting performance. Despite the many benefits, diesel engines emit large quantities of smoke, particulate matter, and NOx, leading to environmental pollution and health concerns. In addition, the depletion of reserves of fossil fuels is the result of both widespread usage and substantial demand, both of which have contributed to the problem. There are now stringent laws in place regarding pollution levels. The depletion of petroleum supplies, along with this challenge, has underscored the need for alternative and environmentally-friendly energy sources [4].

Due to the worldwide depletion of fossil fuel supplies, nations are actively exploring alternative energy sources as substitutes for traditional fossil fuels. Oils made from plant-based products may be able to serve as a viable alternative to conventional diesel fuel, according to the findings of numerous studies that have been conducted to investigate the possibility of replacing conventional diesel fuel using oils derived using crops, vegetables, as well as animal fats. [6] These studies have led researchers to the conclusion that conventional diesel fuel may be replaced by oils derived via vegetables and plants. The investigation of other sources of energy for engines with internal combustion is a worldwide endeavor aimed at mitigating substantial petroleum usage and promoting energy source diversification. Biodiesel has garnered attention as a viable substitute for engines with compression ignition owing to its comparable characteristics to conventional diesel fuel and its advantageous environmental attributes in comparison with other alternative fuel options. An extraction technique is used to produce biodiesel, which may be made from either edible or non-edible vegetable oils. This fuel source is well recognized for its renewable nature, lack of toxicity, and ability to biodegrade. Because biodiesel contains oxygen, it helps to reduce the release that are produced by engines, which in turn improves the performance of the engine and the combustion process. Because of the many factors that contribute to its feasibility, biodiesel is increasingly getting the attention it deserves as a viable alternative fuel that might be used in internal combustion engines (ICE). It finds significant use either as a standalone fuel or in different ratios when blended with mineral diesel [5]. The identification of a viable and environmentally-friendly substitute for conventional fuels has emerged as a paramount concern for several countries. In the future, it is anticipated that this technology would assume a substantial role across diverse sectors. Biodiesel is classified as a sustainable fuel that does not rely on petroleum resources. It is mostly comprised of triglycerides obtained from harvested vegetable oils. The compound offers a multitude of advantages, such as its non-toxic nature, ability to degrade naturally, minimal release , and enhanced lubricating properties [3]. Because biodiesel has similar properties to diesel fuel and is compatible with traditional diesel engines, it has a significant amount of promise as a viable alternative to diesel fuel. As a result, only minor adjustments are required to use biodiesel. There is a possibility that biodiesel might be produced from renewable energy sources like vegetable oil, unused cooking oils, as well as animal fat [1]. The current research examines the viability of utilizing blends of hemp biodiesel in diesel engine specifically focusing on its performance and emission characteristics in contrast to diesel fuel, which serves as the reference fuel.

2. Experimental procedure and specifications

The studies were conducted with a computerized research engine, namely a single cylinder, 4 stroke, direct injected, water cooled diesel engine manufactured by Kirloskar. Table 1 presents the technical specs of the engine. The application of loads to the engine is facilitated by the use of an eddy current dynamometer. The emissions of un burnt hydrocarbons (UBHC), carbon monoxide (CO), carbon dioxide (CO_2) and nitrogen oxides (NO_X) were quantified by the use of the AVL DIGAS 444N 5 gas analyzer. The AVL 437 Smoke meter, which was made by AVL, was used in order to do the measurement of the opacity of the smoke. For the purpose of determining the temperature of the exhaust gases at their outlet, a thermocouple of type K was installed. The researchers used a data gathering device to gather data from combining the combustion analyzer along with the thermocouple.

Table 1: Diesel engine specifications

Manufacturer	Kirloskar
Cylinder	Single
Bore	87.5 mm
Stroke	4 stroke
Type of Cooling	Water cooled
Power	3.5 kW@ 1500 rpm
Stroke	110 mm
Cylinder Volume	661 cc
CR range	12 – 18
Dynamometer	Water-cooled with loading unit, eddy current type.
Injection variation	0 - 25° bTDC

Fig 1: Experimental setup

The engine was run through a range of loads, spanning no load to a complete load, with an output of 3.5 kW. The configuration for experimentation is shown in Figure 1 above. The bio-diesel was produced from hemp vegetable oil using standard transesterification procedures outlined in ASTM D6751. The resulting fuel successfully adhered to the specified criteria. Table 2 presents a comparative analysis of the characteristic features of hemp biodiesel with conventional diesel fuel.

Table 2: Fuel characteristics for hemp bio-diesel vs diesel.

Fuels	**Hemp biodiesel**	**Diesel**	**ASTM Standard**
Flash Point (°C)	181	53	D 9358T
Calorific Value (kJ/kg)	39909	42995	D 4809
Density (kg/m^3)	870	830	D 287
Cetane number	51.63	52	D 613
Kinematic Viscosity (m^2/sec) @ 40°C	4.89 x 10^{-6}	2.09 x10^{-6}	D 445

The following is a list of the fuels, blends of biodiesel and operating conditions that were used during the experiment.

Fuels and blends of bio-diesel used

Standard diesel fuel
H-10 –bio-diesel (10%) + diesel fuel (90%)
H-20 – bio-diesel (20%) + diesel fuel (80%)
H-30 – bio-diesel (30%) + diesel fuel (70%)
H-40 – bio-diesel (40%) + diesel fuel (60%)

Operating conditions

i) Injection timing : 23° bTDC..
ii) Injection pressures : 210 bar.
iii) Compression ratios : 17.5:1

3. Results and discussion

The research comprised the measurement as well as assessment of performance and emission parameters of a diesel engine powered with hemp biodiesel blends and standard diesel fuel.

3.1. Performance parameters

During experimentations, the following performance parameters were determined for blends of hemp bio-diesel and also diesel fuel.

3.1.1.Brake specific fuel consumption

Figure 2 illustrates the relationship between brake specific fuel consumption (BSFC) and brake power. As the load on the engine rises, the brake specific fuel consumptions (BSFC) drops for both hemp biodiesel blends and conventional diesel fuel. The reason for this phenomenon is because the temperature within the cylinder is elevated under high load conditions, resulting in an improved combustion process that subsequently reduces fuel consumption. However, there is a positive correlation seen between the proportional share of biodiesel on the blend and the corresponding rise in this particular variable. Due to the comparatively lower heating values of biodiesel blends in comparison to traditional diesel fuel, a greater quantity of biodiesel blend is necessary to provide a same amount of energy. The full load BSFC values for hemp biodiesel blends H-10, H-20, H-30, and H-40 are 0.39, 0.42, 0.45, and 0.47 kg/kW-hr, respectively, while diesel fuel exhibits a BSFC value of 0.41 kg/kW-hr.

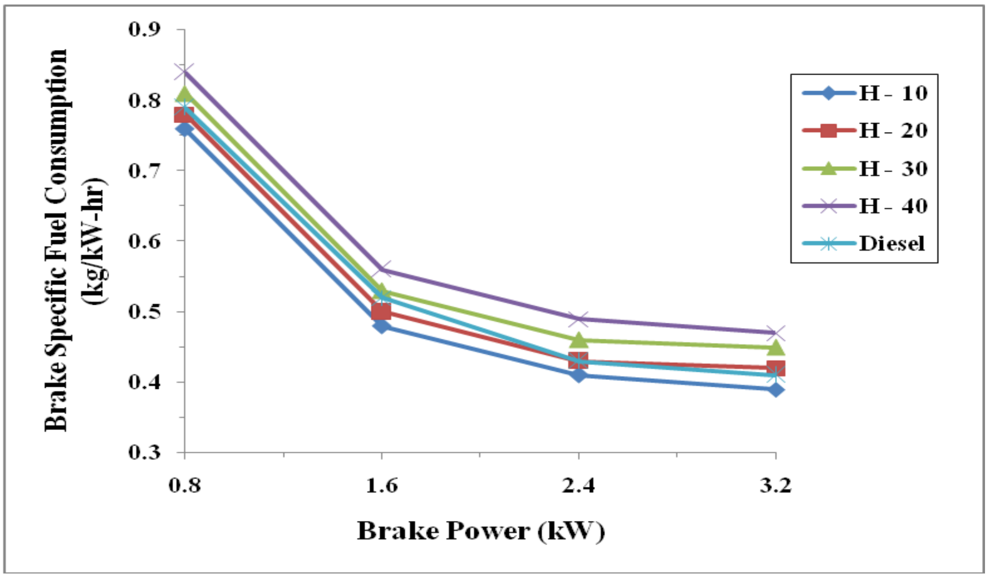

Fig 2: Variation in BSFC/BP.

3.1.2.Brake thermal efficiency

Figure 3 illustrates the relationship between the change of the brake thermal efficiency (BTE) and the brake power (BP). As the load on engine grows, the brake thermal efficiency (BTE) similarly improves for all blends of hemp biodiesel as well as diesel fuel. The rationale for this phenomenon is because in a cylinder, the temperature increases significantly under high load conditions, resulting in an enhanced combustion process. However, the decline in calorific value is seen as the proportion of biodiesel within the blend grows. This is because of the fact that the calorie content of blends falls with higher biodiesel concentration. In addition to this, a rise in the quantity of biodiesel in fuel blends leads to an increase in viscosity. This increase in viscosity negatively impacts the atomization of blend inside the cylinder, resulting in a drop in brake thermal efficiency (BTE) of the engines. The values of BTE for blends of hemp biodiesel at full load are 24.26%, 22.67%, 21.45% and 20.56% respectively compared to 23.35% for diesel fuel.

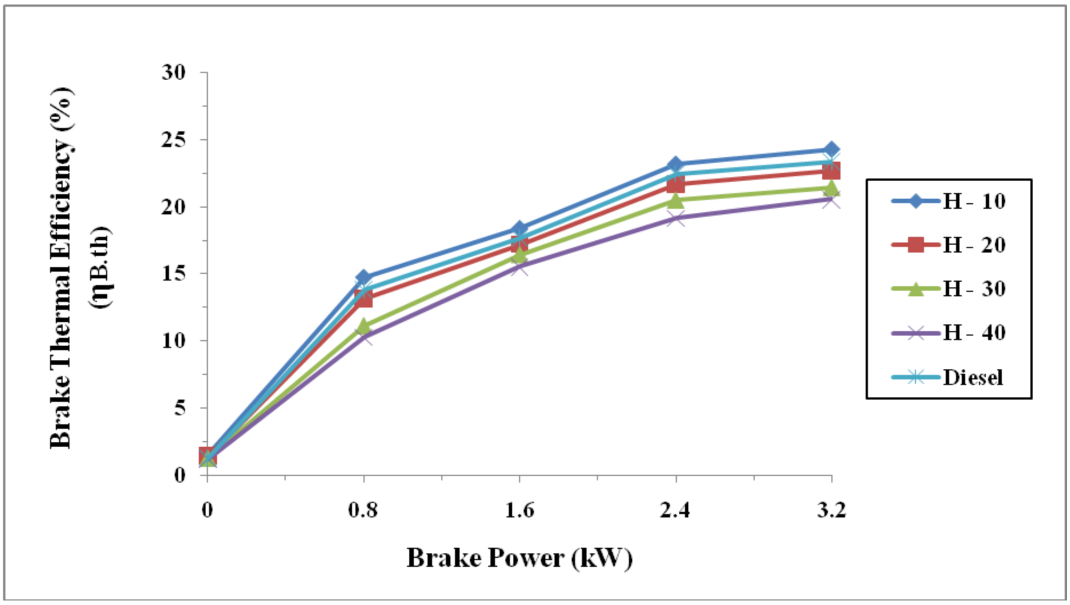

Fig 3: BTE/BP variation.

3.1.3. Exhaust gas temperature

Figure 4 illustrates the relationship between exhaust gas temperature (EGT) and brake power (BP). As the applied load intensifies, the exhaust gas temperature (EGT) for the engine shows an upward trend in case of both hemp biodiesel blends and conventional diesel fuel. The rationale for this phenomenon is that under increased load conditions, a greater amount of fuel is necessitated for combustion. Furthermore, there is a positive correlation between the proportion of biodiesel in the blends and the observed rise in this phenomenon. The observed phenomenon may be related to the rise in the proportion of biodiesel in the combinations, which leads to a rise in both flame temperature and combustion temperature. This can be explained by the increased oxygen proportion present in biodiesel blends. Pure diesel has a modest increase in exhaust gas temperature (EGT) when compared to blends of hemp biodiesel across all loads, owing to its longer ignition delay time. The EGT values at full load for hemp biodiesel blends H-10, H-20, H-30 and H-40 are 281°C, 295°C, 306°C and 318°C respectively compared to 278°C for diesel fuel.

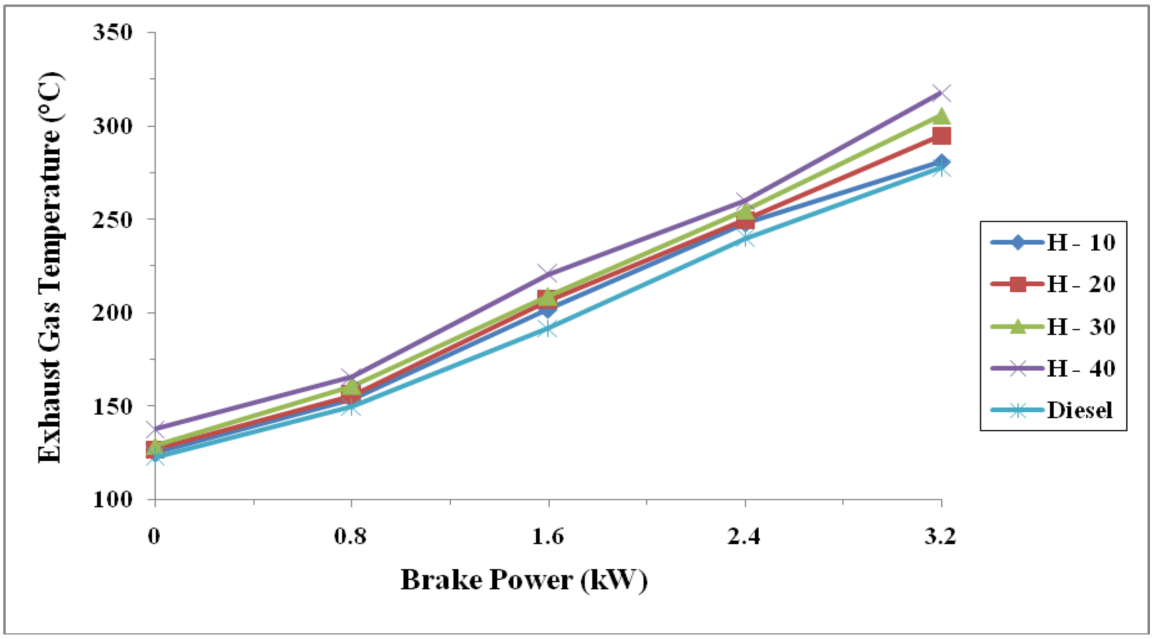

Fig 4: EGT-BP variation.

3.2 Emission parameters

During experimentations, the following emission parameters were determined for blends of hemp biodiesel and also diesel fuel.

3.2.1.Un burnt hydrocarbon

Figure 5 illustrates the relationship between BP and UBHC emissions. As the engine load rises, there is a corresponding increase in UBHC emissions for all blends of hemp biodiesel. This may be attributed to the inadequate delivery of oxygen during the combustion process. The emissions of UBHC from the engine are found to be greater when using diesel fuel as compared to blends of hemp biodiesel, regardless of the engine load. Moreover, as the proportion of biodiesel in the blends rises, there is a corresponding drop in UBHC emissions. The improved combustion process seen in hemp biodiesel blends may be ascribed to the higher concentration of oxygen present in these blends. The emissions of UBHC at full load for several blends of hemp biodiesel, namely H-10, H-20, H-30, and H-40 are recorded as 78, 70, 62, and 55 ppm accordingly. In comparison, diesel fuel exhibits emissions of 99 ppm.

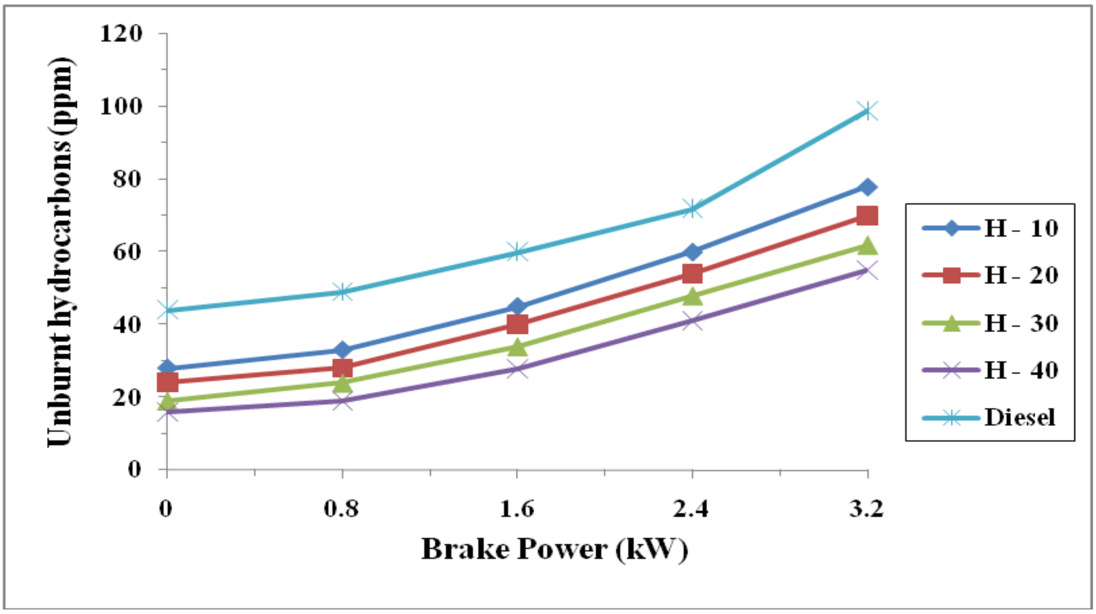

Fig 5: UBHC emission-BP variation

3.2.2.NO$_X$ emisssions

In the following Fig. 6, it is shown that the variations of NO$_X$ emissions with BP. As the engine load rises, there is a corresponding rise in NO$_X$ emissions for all blends of hemp biodiesel as well as diesel fuel. The engine exhibits greater NO$_X$ emissions when fueled with diesel compared to blends of hemp biodiesel across all loads. Furthermore, as the amount of biodiesel in the blends rises, the NO$_X$ emissions likewise increase. The full combustion seen in biodiesel blends may be due to the increased oxygen levels present in these fuels. The burning of blends in its entirety yields elevated temperatures, leading to the dissociation of valence oxygen and subsequently resulting in increased emissions of NO$_X$. The recorded nitrogen oxide emission levels at full load for hemp biodiesel blends H-10, H-20, H-30, and H-40 are 996, 1113, 1140, and 1188 ppm accordingly, in contrast to the emission level of 1210 ppm observed for diesel fuel.

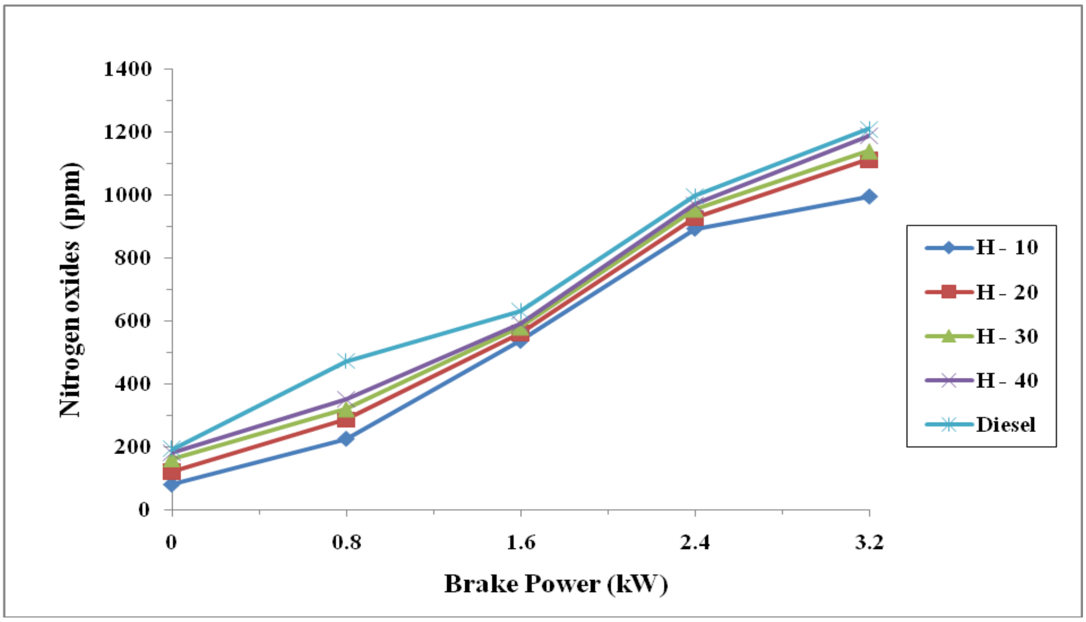

Fig 6: BP-NO_X release variation.

3.2.3. Discharge of Carbon Monoxide

Figure 7 illustrates the relationship between CO emissions and BP. As the load is augmented, the emissions of CO exhibit a decline in the case of biodiesel blends. This phenomenon enhances the combustion process that occurs in the presence of elevated cylinder temperatures at high load conditions.

Nevertheless, at all levels of use, the emissions of CO are very low for biodiesel blends as to conventional diesel fuel. Furthermore, as the proportion of biodiesel in the blends grows, there is a corresponding drop in CO emissions for these biodiesel blends. The observed phenomenon of enhanced oxidation in biodiesel blends may be related to the higher oxygen concentration present in these blends. The carbon monoxide emission levels at full load for hemp biodiesel blends H-10, H-20, H-30, and H-40 are recorded at 0.28%, 0.26%, 0.24%, and 0.22% by volume, respectively, in comparison to the emission level of 0.33% per volume for conventional diesel fuel.

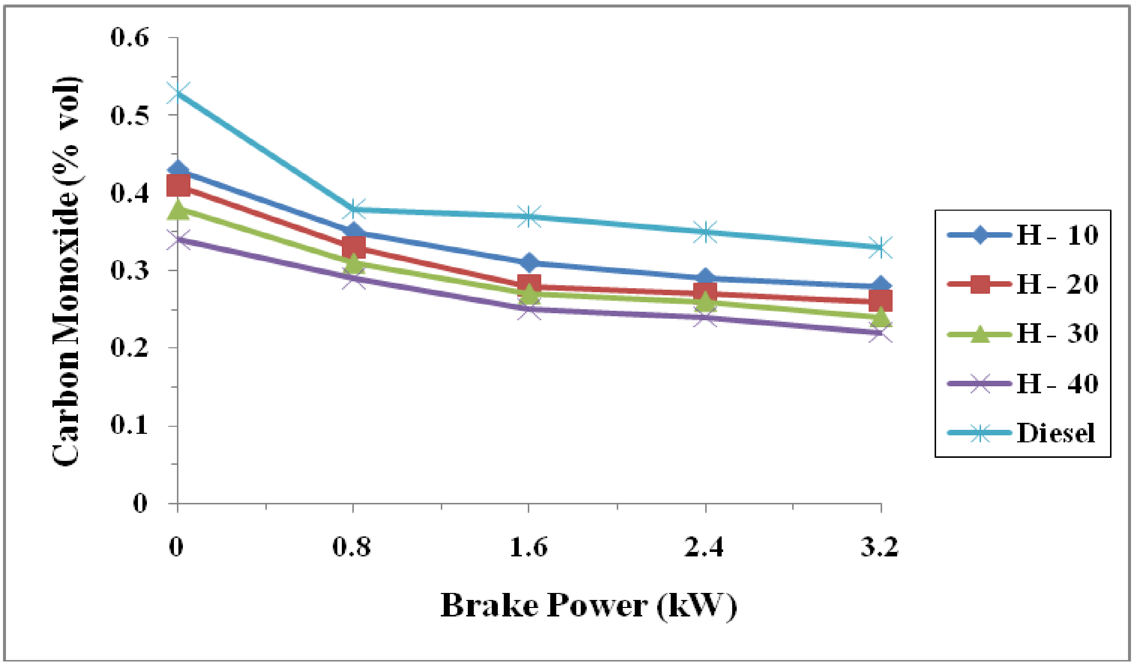

Fig 7: BP-CO emission variation.

3.2.4.Emissions of carbon dioxide

The graph in Figure 8 illustrates the relationship between CO_2 emissions and BP variability. In conventional biodiesel blends and conventional diesel fuel, a rise in load results in a corresponding increase in emissions. This may be attributed to the enhanced efficiency of the combustion process at higher cylinder temperatures. The observed phenomenon of increased temperature is also shown to be positively correlated with greater biodiesel percentage in the biodiesel blends. This is due to the higher oxygen concentration present in biodiesel blends, which enhances the combustion process and subsequently leads to elevated temperatures. The elevated temperature subsequently induces the full oxidation of CO to CO_2, leading to an increased release of CO_2 emissions. In all load scenarios, it has been shown that the levels of CO_2 emissions are greater for biodiesel blends in comparison to diesel fuel. This finding is indicative of the whole combustion process. The values of CO_2 emissions at full load for hemp biodiesel blends H-10, H-20, H-30 and H-40 are 6.8%, 8.1%, 8.8% and 9.2% vol respectively compared to 5.8% vol for diesel fuel.

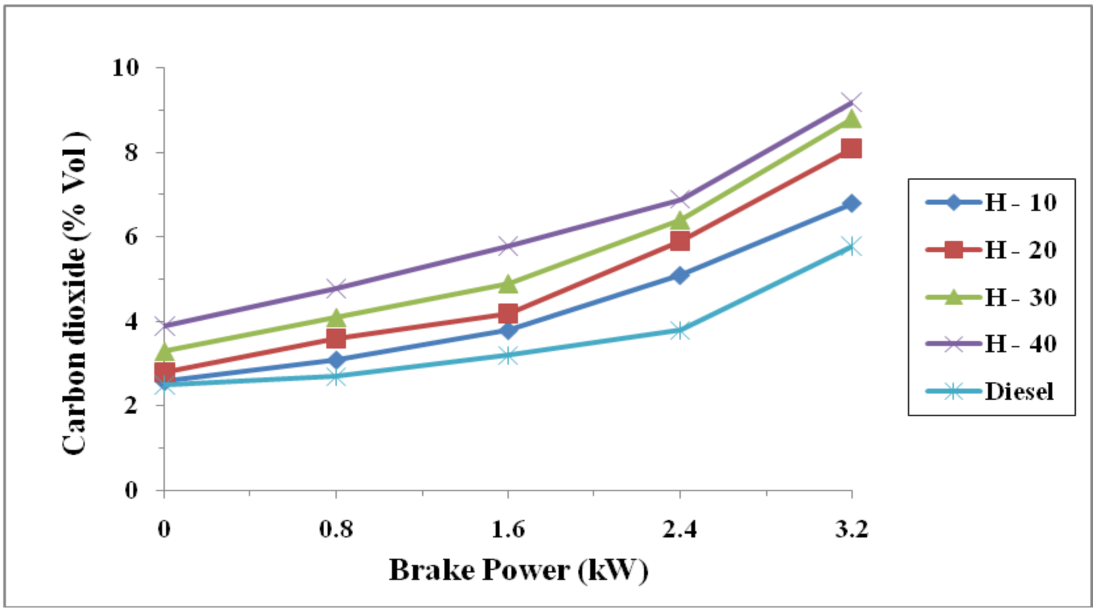

Fig. 8. BP-CO_2 emission variation.

3.2.5.Opacity of smoke

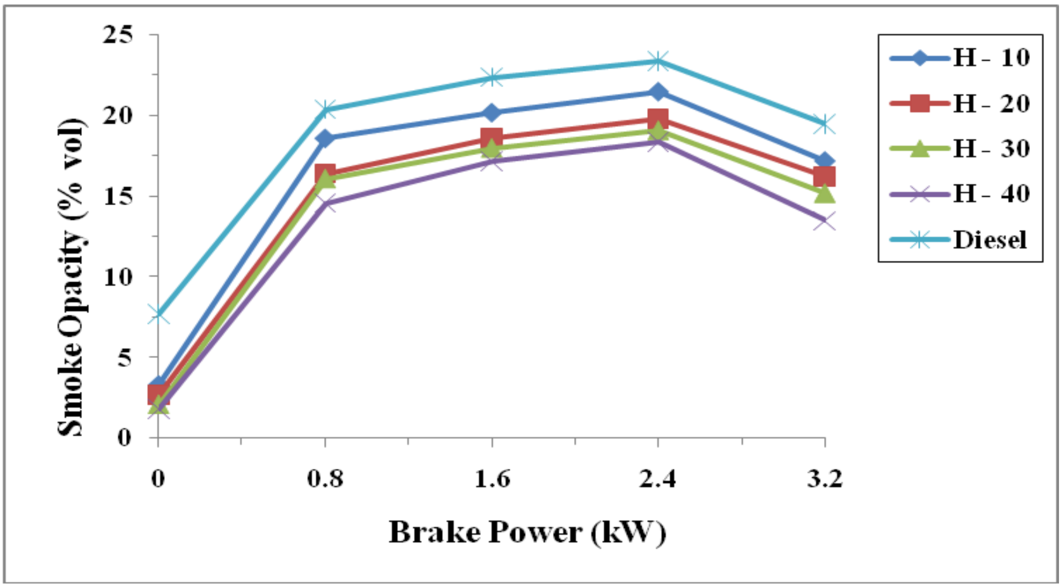

Fig 9: BP influences on smoke opacity.

The phrase "smoke opacity" refers to the measure of smoke intensity. The smoke opacity is reduced by the process of complete combustion of both the air and fuel mixtures inside the combustion chambers. Figure 9 illustrates the relationship between smoke opacity and BP. In the context of load variation from zero to full load, it is observed that the smoke opacity tends to rise up at smaller loads and decrease at higher loads for both hemp biodiesel blends and conventional diesel fuels. The observed phenomenon might be related to an inadequate blending of droplets of fuel with air under lower loads, resulting in suboptimal combustion. Conversely, during greater loads, a more effective blending of fuel droplet with air occurs, leading to improved combustion and subsequently reduced smoke opacity . The decrease in smoke generation in exhaust gases may be linked to the increased oxygen content present in blends of biodiesel, resulting in complete fuel oxidation. This drop is seen with an increase in the proportion of biodiesel in the blends. Based on the findings as shown in Figure 12, it is clear that the visibility of the smoke is consistently lower for biodiesel blends in comparison to diesel fuel across all load conditions. This discrepancy serves as an indicator of the more thorough combustion process associated with biodiesel blends as to diesel fuels. The values of smoke opacity at full load for hemp biodiesel blends H-10, H-20, H-30 and H-40 are 17.2%, 16.2%, 15.2% and 13.5% vol respectively compared to 19.5% vol for diesel fuel.

4. Conclusions

In order to evaluate the efficiency of hemp biodiesel blends, namely H-10, H-20, H-30, and H-40, in comparison to diesel fuel, a diesel engine was operated under identical circumstances. The objective was to compare the aforementioned blends with diesel fuel, which served as the reference fuel. The following statements represent the findings or deductions.

1. As the load on the engine grows, BSFC drops, but BTE and EGT increase for both blends of hemp biodiesel and diesel fuel. The BSFC exhibited a drop of 4.88% for the H-10 blend, while an increase of 2.44% was seen for the H-20 blend, 9.76% for the H-30 blend and 14.63% for the H-40 blend, as to the BSFC of diesel fuel that was measured at full load conditions. The BTE for H-10 rose by 3.89%, but it declined by 2.91% for H-20, 8.14% for H-30, and 11.95% for H-40 blend, as compared to the BTE of diesel fuel at full load. The EGT exhibited a rise of 1.08% for the H-10 blend, 6.11% for the H-20 blend, 10.07% for the H-30 blend and 14.39% for the H-40 blend in comparison to the EGT observed for diesel fuel at full load condition.
2. The inclusion of a higher proportion of biodiesel derived from hemp in the blend results in an increase in BSFC and EGT, while BTE declines.
3. In the emission assessment, it was observed that when the load rises, there is an increase in UBHC, CO_2 and NO_X emissions for all biodiesel blends as well as diesel fuel. Conversely, the emissions of CO decrease for all tested fuels under the same conditions. The emissions of UBHC were seen to exhibit a reduction of 21.21% for H-10, 29.29% for H-20, 37.37% for H-30 and 44.44% for H-40 blend in comparison to the UBHC emissions produced by diesel fuel at full load condition. The emissions of CO_2 had a notable rise across different blends, namely by 17.24% for H-10, 39.66% for H-20, 51.72% for H-30 and 58.62% for H-40 when compared to the emissions from diesel fuel at full load conditions. The study saw a reduction in NO_X emissions of 17.69% for H-10, 8.02% for H-20, 5.79% for H-30 and 1.82% for H-40 blends as compared to the NO_X emissions produced by diesel fuel at full load condition. The emissions of CO shown a reduction of 15.15% for the H-10 blend, 21.21% for the H-20 blend, 27.27% for the H-30 blend and 33.33% for the H-40 blend in comparison to emissions of CO produced by diesel fuel at full load condition.
4. The smoke opacity exhibits an upward trend at lower loads and a downward trend at greater loads for both biodiesel blends and conventional diesel fuel. The smoke opacity of H-10 blend reduced by 11.79%, H-20 blend decreased by 16.92%, H-30 blend decreased by 22.05% and H-40 blend decreased by 30.77% when compared with smoke opacity of diesel fuel when measured at full load.
5. As the proportion of biodiesel in the blends is increased, there is a fall in smoke opacity, CO emissions and UBHC emissions. However, there is rise in CO_2 and NO_X emissions for biodiesel blends.

6. However, it is observed that biodiesel blends exhibit lower levels of CO, smoke opacity, UBHC and NO_X emissions compared to diesel across all loads. Conversely, biodiesel blends result in greater levels of CO_2 emissions compared to diesel.

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