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Investigation of mustard seed biodiesel as alternative fuel for compression ignition engine

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Abstract The global demand for energy is exponentially increasing, driven by population growth and technological advancements. Most of the sources of energy used worldwide are fossil fuels and natural gas. However, the limited availability of these energy resources is a significant challenge faced currently. In the present work, an investigation of mustard seed biodiesel is carried out as an alternative energy source. The transesterification process was employed to prepare biodiesel and experimental method were implemented to determine fuel properties. The density and viscosity of pure mustard oil were high compared to pure diesel. Additionally, the amount of load applied and the different blend types determine the overall engine performance. This study showed that mustard seed biofuel blended with diesel is capable of running the diesel engine and can be used as the best alternative energy sources.

Keywords: mustard seed, mustard oil, biodiesel, transesterification, engine performance.

1. Introduction

The development of human beings is completely accompanied by energy needs which include fossil energy sources. Coal, oil, and natural gases are examples of fossil fuels that are nonrenewable energy sources exhausted within a short period [1, 2]. As a result of the expansion of industry, agricultural machinery, and automobiles, petroleum products, i.e. by-products of fossil fuels increased rapidly. It is stated that around 75 million barrels of petroleum reserves are consumed daily [3]. Consequently, fossil fuel resources have diminished rapidly and many countries depend on the import of fossil fuels [4]. In several countries such as Nigeria, scarcities of fuel exist [5] and in the United States, two-thirds of the petroleum needs are met by imports [4]. This factor shows that fossil fuels are going to be exhausted [6]. Apart from its advantages, it is a major contributor to air pollution. This causes ozone depletion and pollution in the atmosphere [2]. In the past 50 years, global warming has been caused by the production and consumption of fossil fuels [7]. Combustion of fossil fuels is identified one to another by the per cent increase in carbon dioxide content in the global atmosphere [8]. 150 years ago, the burning of coal, oil, and natural gas caused an increase of 25% carbon dioxide level in the environment's atmosphere. Over the past century, the CO_2 level has increased from 280 to 379 parts per million (ppm), while the methane level rose abruptly from 715 to 1774 parts per billion (ppb) [7]. Furthermore, because of socio-economic and political instability in many oil-producing countries, oil costs have increased worldwide. The increase in global warming, growing demand, and rising fuel prices caused to search for substitutive renewable energy resources [9]. Currently, biofuel, which is produced from vegetable oil, seeds, etc., is considered the best alternative to reduce dependence on fossil fuels [4]. Biofuels are considered a trusted alternative to fossil fuels and can be used in the direct fuel injection system [10]. It also gives the best blending option with diesel and reduces emissions [11].

Van Gerpen et al. [12], studied the history of biodiesel development, production practices, and the technology to safely use the fuel. They observed vegetable oil has potential as an alternative energy source. However, vegetable oil alone will not solve dependence on foreign oil; new oil crops could allow biodiesel to make a significant contribution in the future. The use of biodiesel fuel blends provides a reasonable and effective approach to reduce exhaust emissions and improve thermal efficiency with diesel fuel. Mustard oil biodiesel fuel blends were tested in depth on combustion, performance, and emissions at different engine loads, and the results showed that emissions were reduced dramatically in the case of biodiesel addition to test fuels [13]. The performance and emission characteristic of C.I engine depend on various factors like fuel injected, timing of fuel injection and fuel injection pressure. Steam injection applied to single cylinder four stroke method could decrease NOx and engine performance. Additionally, The emission of CO are lower at maximum loads for the methyl ester of cashew nut shell oil when compared with baseline of diesel [14–16]. Palani et al. [17] examined the impact of operation conditions, engine tests and Diesel fuel tests on engine performance and emission characteristics. The results of conventional diesel and diesel-biodiesel blend show that the diesel-biodiesel blend has a shorter ignition delay, a lower heat release rate, and is marginally more efficient. When using biodiesel blends, emissions like CO, HC, and particulate matter are minimized.

Renewable energy sources and domestic feedstock are required to produce biodiesel, which has higher degradability than fossil fuels and shows lower emissions [10]. It is produced from vegetable oil or animal fat by chemical reaction and it is also used in diesel engines with or without blending of diesel [18]. Three billion people are suffering from severe health damage because of using solid fuels [17, 19, 20]. Biofuel has a great role in enhancing the health of people, despite the increase in production and use of biofuels in many countries; still, many African countries are yet to develop the production and usage of biofuels [1–5].

In Ethiopia, biomass is the primary source of energy, accounting for 91 percent of total energy consumption. Ethiopia's CO_2 emissions have climbed from 6.5 million tons in 2010 to 17 million tons in 2020 as a result of its reliance on biomass for cooking [21]. Castor biodiesel was made from castor oil and put through its paces in a CI engine. Nanoparticles are added to the fuel to improve oxygen concentration. The castor biodiesel was then blended in various ratios with diesel. The blended fuel is tested in a diesel engine to determine its performance and emission characteristics. The generation of HC, CO, and smoke emissions was concentrated due to the addition of cerium oxide nanoparticles to the castor biodiesel blend. The NOX emissions, on the other hand, increased as a result of complete combustion. The maximum HC, CO, and NOX emissions generated by diesel at 2.29 kW engine brake power are 10.11 %, 9.19 % and 5% more than those emitted by castor biodiesel [17]. Biodiesel manufacturing uses waste animal fats as a feedstock Catalysts include sulfuric acid (H2SO4) and potassium hydroxide (KOH), with methanol serving as the alcohol. Acid catalyst (H2SO4) was a more active biodiesel catalyst than KOH in biodiesel manufacturing [22]. However, there are alternative sources of energy which have diverse varieties of feedstocks like mustard seeds, jatropha, castor seeds, pumpkin seeds, argemone, cotton seeds, avocado, coffee residues, bottle gourd, neem, etc. despite these resources still many seeds are not explored for the use of biofuel production.

This study focused on preparation of mustard seed biodiesel as alternative fuel for compression ignition engine. Mustard seed was chosen to prepare biodiesel based on its abundant availability and sustainability in large rural areas of Ethiopia. Since the petroleum reserves are lower in this country, the use of biofuels can reduce import dependence and thereby increase the foreign exchange reserves. In this context, the need of renewable resources becomes increasingly prominent.

2. Methodology and materials

2.1. Determination of fuel properties

The experimental setup and procedures for measuring density, viscosity, flash point, fire point, cloud point, and pour point are described as follows.

Density. At a particular temperature, density is defined as the mass per unit volume of any liquid. The density of a liquid divided by the density of water is known as specific gravity [23, 24]. Density is critical in diesel engines because it influences fuel performance factors such as cetane number, heating value, and viscosity, all of which are directly linked to density. Figure 1 shows the fuel density measurement in weight balance. The temperature has a significant impact on density. With the rising temperature, the density of vegetable oil falls linearly.

Viscosity. The most important property of biodiesel fuel is viscosity, which has an impact on the performance of fuel viscosity injection equipment, particularly at low temperatures when increased viscosity affects fuel fluidity. Poor atomization of the fuel spray and less precise fuel injector functioning are caused by high viscosity [25]. The Redwood Viscometer was used to determine the viscosities of various fuels (see Fig. 2). The time of fall of the 50-cc sample was determined under controlled conditions through a standard oil tube. This time was recorded as the time for Redwood. Corresponding kinematic viscosity was obtained from standard formulae for redwood viscometer and the value was checked by computing the same for distilled water. Finally, measured values of kinematic viscosity were presented.

Figure 1. Density measurement in weight balance.

Figure 2. Redwood Viscosity meter.

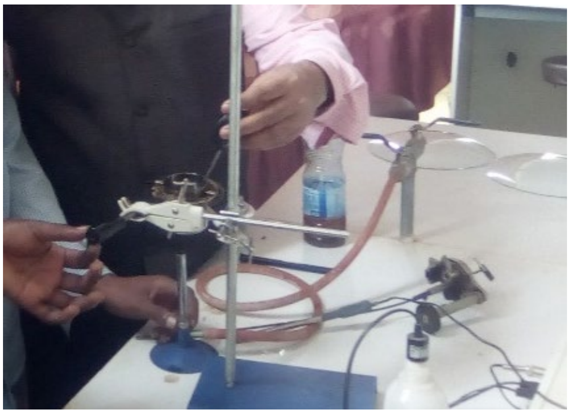

Figure 3. Determining the flash and fire point of the fuel.

Flash point and fire point. The flashpoint of biodiesel was employed as a technique to keep the amount of unreacted alcohol in the finished fuel to a minimum [26]. The flashpoint of test fuels was determined using the Cleveland Close device (see Fig. 3). The sample placed in the closed-cup tester was gradually heated by constant stirring. A flame was placed into the oil cup for every 2°C increase in the temperature of the oil. The fuel's flashpoint is defined as the lowest temperature at which the fuel vapor flashes and then vanishes when exposed to a test flame.

Heating value. Using an oxygen bomb calorimeter, the heating values of the fuels used in this research were calculated experimentally. At constant volume, one gm of the previously weighed sample was burned. From the reading, the combustion heat was computed [27].

Engine test. Alternative energy source from biofuel has influence on dynamic performance of the engine based on the content of biodiesel. The experimental setup for monitoring the various engine performance characteristics is described in this section. A four-stroke, single-cylinder, water-cooled, computerized direct injection diesel engine was employed in this study [28]. The engine and dynamometer assembly, air inlet and exhaust system, cooling water inlet and outlet system, fuel inlet system, and measuring facility are all part of the experimental setup, as shown in the diagrams below.

2.2. Biofuel preparation

In this study, transesterification process was employed to produce biodiesel from mustard oil since this process favored method to prepare fuel having excellent quality [6, 7, 24]. First, 150 mL (1 N) NaOH was diluted with 250 mL (90% pure) methanol. In a glass container, this mixture was swirled until the NaOH was fully dissolved in methanol (see Fig. 4). The mixture would become liquid as a result of the exothermic reaction. Methoxide, a strongly corrosive base that is poisonous to human skin, is the name of this solution. During the processing of methoxide, health precautions should also be taken to prevent skin contamination [9–11, 29]. Methoxide was then slowly added to 1 liter of mustard oil that had been heated to around 55 degrees of Celsius. After that, the sample was mixed in a glass jar for 5 minutes.

Figure 4. Mixing of methoxide and mustard oil.

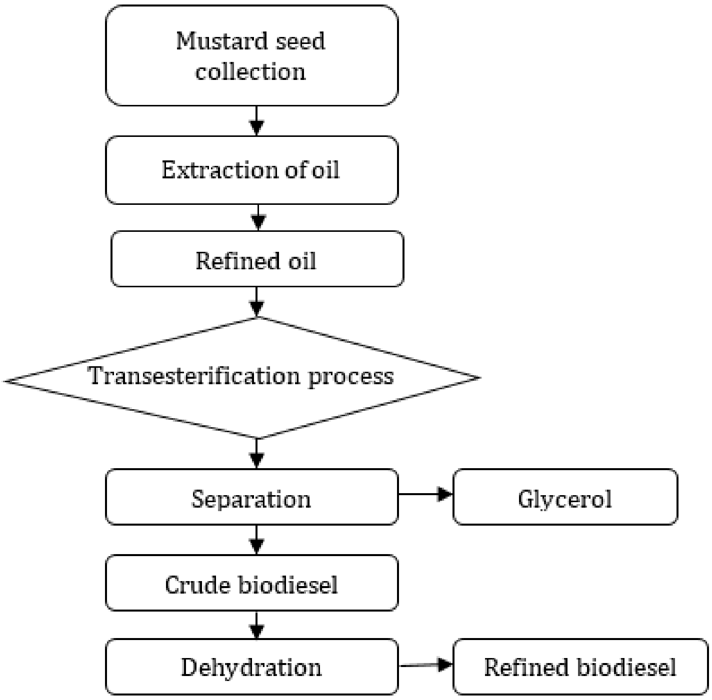

Figure 5. Schematic diagram of the biodiesel production methodology.

The mixture was then left for 24 hours to allow sufficient time for the glycerol and ester to separate effectively. The mixture was settled down gradually, with 100 percent biodiesel at the top and glycerol at the bottom. The heavier layer was then separated, either by gravity separation or centrifugation. If there are impurities in the mustard oil, a thin white layer forms between the two layers in some cases. This thin layer was made up of soap and other impurities. Moisture (100 degrees of Celsius vaporization temperature) and methanol (60 degrees of Celsius vaporization temperature) were present in the biodiesel generated in the above process, as well as some soap. The methanol can be extracted by vaporization if the soap level was low enough (300 ppm – 500 ppm), and the methanol was usually dry enough to recycle back into the reaction. Methanol is also utilized in biodiesel as a cosolvent for soap. At greater soap levels, the soap must precipitate as a thick sludge when methanol was removed. In any event, heating the biodiesel above 100 degrees of Celsius will remove the moisture as well as the methanol. We used food-grade quality mustard oil was used instead of raw mustard oil in our analysis to ensure that the vegetable oil contained less contaminants. Figure 5 explains methodology of biodiesel preparation starting from mustard seed to the final refined biodiesel.

3. Results and discussions

3.1. Fuel testing to determine the physical properties

Mustard oil and diesel are mixed in this experiment. B10 and B20 are the designations for mustard-diesel blends. The density, viscosity, kinematic viscosity, dynamic viscosity, flash point, and fire point of the mixes and pure mustard biofuels were all measured. Finally, a comparison with pure diesel was made, and conclusions were derived (see Tab. 1).

Table 1. Thermo-physical properties of fuels.

Fuel Type	Density (kg/m^3) at 20°C	Kinematic viscosity (centistrokes) at 70°C	Flash point (°C)	Fire point (°C)	Pour point (°C)	Cloud point (°C)	Calorific value (MJ/kg)	CN
MB-100%	938	19.80	310	350	-12	3.8	39.51	50
MB+CB-30% + D-70%	859	5.63	90	100	-16.7	-1.3	39.4	53
MB+CB-20% + D-80%	854	4.90	90	95	-19	-7.1	41.3	54
D-100	848	4.15	70	80	-23	-11.4	44	55

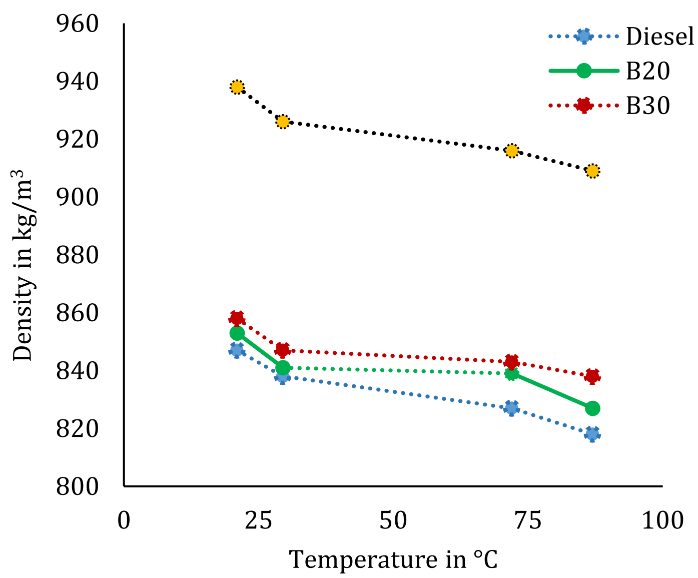

Figure 6. Variation of density with temperature for diesel and biofuel blends.

3.1.1. Density

The density of the fuels reduced as the temperature rose, as presented in Fig. 6. The density of mustard-diesel mixtures were higher than that of fossil diesel. At 20°C, pure diesel has a density of 848.00 kg/m^3 while pure mustard oil has a density of 938.00 kg/m^3. It is observed that B20 is higher from 0.5 to 1.22% compared with pure diesel in the temperature range of 20°C to 80°C and B30 varies from 1.17% to 2.44% higher compared with pure diesel. Whereas the pure mustard biofuel variation was enormously higher compared to diesel from 10% to 11%. By using this blend, there was no preheating required in the CI engine.

3.1.2. Viscosity

The validation of the redwood viscometer was initially done with distilled water. The viscosity of the fuel influences the geometry of the fuel spray; for example, high viscosity promotes low atomization (large droplet size) and high spray jet penetration. A cold engine with high viscosity oil will discharge a solid fuel stream into the combustion chamber, making it difficult to start since a smoky exhaust is almost always present. On the other hand, very low viscous fuel will allow piston and piston wall leakage to pass, particularly after wear, As a result, precise fuel metering is impossible to achieve. Figure 7 illustrates viscosity of fuels decreases as the temperature rose. The viscosity of pure mustard oil (M100) is higher than all other blends whereas the fossil diesel fuel is the lowest. By calculating, we find that B20 is 13.9%, B30 is 27.7%, and M100 is more than 200% more viscous than fossil diesel at a room temperature of 20°C. We also observed that while the blends are heated at about 70°C, the viscosity became close to diesel fuel (3.08 mm^2/sec) but the viscosity of the pure mustard oil was found to be 15.64 mm^2/sec.

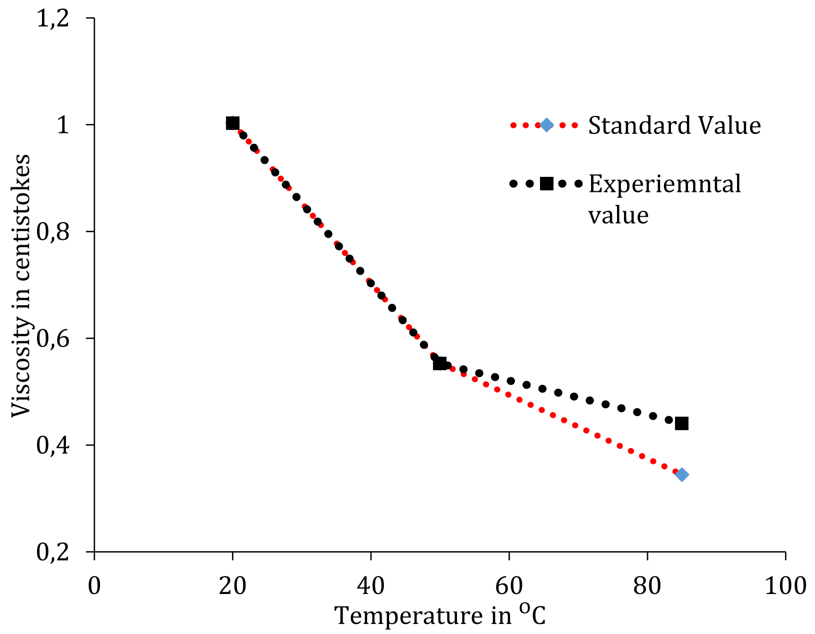

Figure 7. Variation of viscosity at different temperatures for diesel and biofuel blends.

3.1.3. Flash Point and Fire Point

There was a flash and a fire point for each mustard and diesel fuel combination. The flashpoint of pure mustard oil was 310°C, and the fire point was 350°C. The flashpoint and fire point steadily lowered when diesel was added. While mixing mustard with diesel, the following flash and fire points were identified:

3.1.4. Calorific Value of Fuel

It is found that diesel fuel has a heating value of around 44 MJ/kg, while mustard blend heating values have 41.3 MJ/kg and 39.4 MJ/kg, respectively. As the mustard mixture increases, the heating value of the mix falls. This is owing to the reduced heating value of mustard oil.

3.2. Variation of brake specific fuel consumption with brake power

The difference between brake specific fuel consumption (BSFC) and brake power (BP) for various diesel blends is shown in Fig. 8. The graph illustrates that for low percentage loads, BSFC for biodiesel blends is higher. As the percentage load grows, it likewise lowers. The graph also indicates that as the biodiesel blend increases, so does the amount of actual fuel used. The link between the volumetric fuel injection procedure, specific gravity, viscosity, and heating value accounts for this. As a result, due to its higher density and lower heating value, more biodiesel mixes are required to create the same amount of energy as standard diesel fuel. Because biodiesel blends have a higher viscosity than diesel fuel, they induce poor atomization and mixture formation, resulting in increased fuel consumption to maintain strength. When compared to diesel fuel, the increase in fuel consumption is minimal.

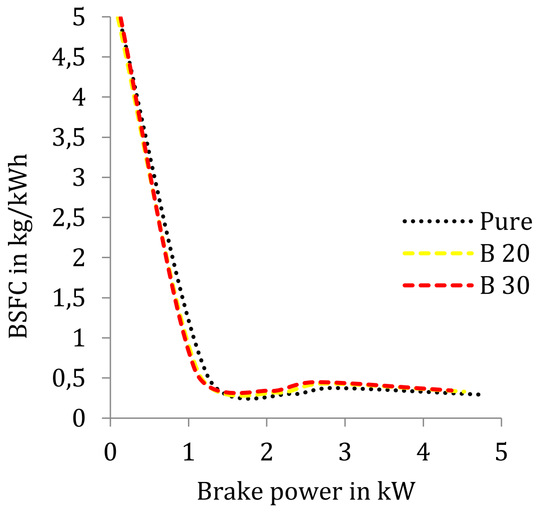

Figure 8. Variation of BSFC with different brake power.

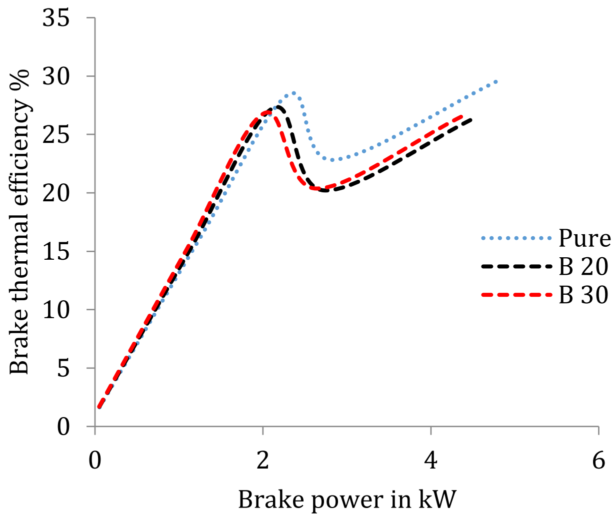

Figure 9. Variation of brake thermal efficiency with brake power.

3.3. Variation of brake thermal efficiency of engine with brake power

Figure 9 represents the relationship between brake thermal efficiency (BTE) (Itb) and BP (kW) for various mustard and diesel blends. The BSFC is a metric that measures overall engine performance. Productivity is inversely related to the BSFC. As a result, the lower the BSFC value, the better the overall output of the engine. The BSFC values, on the other hand, are unreliable for different blends with different heating values, so brake thermal efficiency is used when different types of fuels are felled by the engines. At a 17 kg load, the maximum thermal brake efficiency is 29.59% for D100, 26.41% for B20, and 26.52% for B30. The BTE of the engine was found to increase with increased load and decrease with increased biofuel blends. Pure diesel D100 had the highest BTE at an 8 kg load of 29.59%. BTE increased with increasing load until it reached 12 kg, at which point it began to decrease. The initial increase in BTE was due to complete and high fuel combustion; however, once the load reached full load, the time required for full fuel combustion was decreased, resulting in a slight decrease in BTE. Vegetable oils' basic gravity may have also influenced engine performance at full load speeds. Low for biodiesel blends is also due to poor atomization caused by the higher density and kinematic viscosity of biodiesel blends.

3.4. Variation of exhaust gas temperature with BP

Figure 10 indicates the difference in the temperature of the exhaust gas with BP for differential blends. As the load increases, the temperature of the exhaust gas increases, more fuel is burned inside the cylinder and more temperature is produced, thereby increasing the temperature of the exhaust. With the growth of biofuel blends, the temperature of the exhaust gas also increases. All other biodiesel blends have higher temperatures for exhaust gas than diesel fuel, as can be seen from the curve. For bio-diesel blends, higher exhaust gas temperature but low power output suggests late burning of the high proportion of biodiesel at the start condition. This would result in more heat loss, making combustion less efficient.

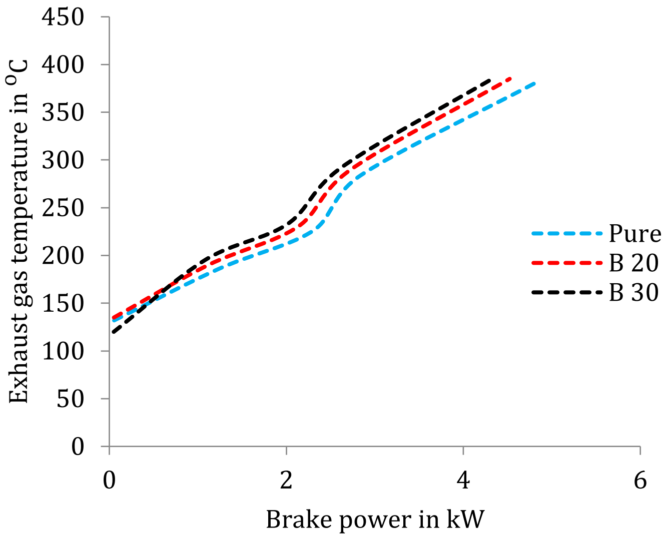

Figure 10. Variation of exhaust gas temperature with brake power.

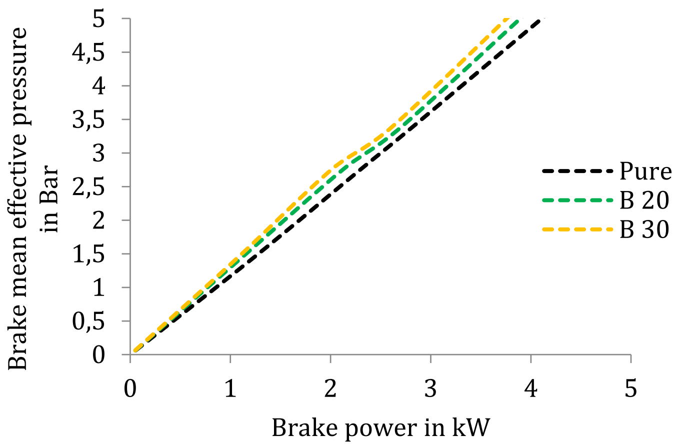

Figure 11. Variation of brake mean effective pressure with brake power.

3.5. Variation of brake mean effective pressure with brake power

The Brake Mean Effective Pressure (BMEP) variance for various biofuel blends with BP is shown in Fig. 11. The mean effective pressure is a reciprocating engine operating quantity and a valuable indicator of the ability of the engine to perform work that is independent of the motor displacement. BMEP is calculated based on the torque measured by the dynamometer. During the experiment with each blend, a small variation of BMEP was observed. The BMEP increases steadily as the engine load increases, with the maximum BMEP for each blend being detected at a 17 kg load. The standard curve shape suggests that proper combustion has occurred in the fuel combustion chamber.

4. Conclusions

From this research, it is evident that mustard seed biofuel blended with diesel can be used to run the diesel engine. The heating values of pure diesel, B20, and B30 are 44 kJ/kg, 41.3 kJ/kg, and 339.4 kJ/kg, respectively. The density of the pure mustard oil is very high compared to the pure diesel and B20, and B30 shows a slightly increase compared to the diesel. Viscosity of the pure mustard oil is very high compared to the pure diesel and B 20 and B 30 show a slight increase in viscosity compared to the diesel fuel and decrease with an increase in temperature. When compared to pure diesel, brake-specific fuel consumption reduces with increased brake power and is nearly the same for B 20 and B 30. Brake thermal efficiency increases as load increases, and brake thermal efficiency decreases as blends increase when compared to pure diesel. Exhaust gas temperature rises with brake power, and the B 20 and B 30 have a slight increase in exhaust gas temperature as compared to pure diesel. When braking power is increased, brake mean effective pressure rises somewhat, and brake mean effective pressure of B 20 and B 30 is slightly higher than pure diesel.

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Additional information

The authors declare: no competing financial interests and that all material taken from other sources (including their own published works) is clearly cited and that appropriate permits are obtained.

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