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An Experimental Study on the Performance, Combustion, and Emission Characteristics of a Direct-Injection Diesel Engine Fueled with Various Blends of Camelina Sativa Biodiesel †

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Abstract: Recently, the utilization and research of biodiesel has become increasingly popular due to its reduced emissions, lower cost, and potential for achieving energy independence. A promising application of biodiesel is in diesel engines, where it can be used as a substitute for traditional petroleum-based diesel fuel. Camelina sativa is an oil seed crop with prospective uses in biodiesel extraction due to its high crop harvest in a year, good net energy ratio, the considerable oil content in its seed, and lower oil extraction expenses. Biodiesel derived from camelina sativa L. is prepared via transesterification. In this study, the prepared biodiesel is blended with diesel at various proportions and is used in an engine to investigate its combustion performance and emission characteristics. From the results, it is evident that the CMB 20 blend (20% of camelina biodiesel and 80% of diesel) shows the better performance among all of the blends used. The brake thermal efficiency of CMB 20 is 23.45%, its specific fuel consumption is 0.355 kW/kg hr, and it also produced less emissions when compared to other blends.

Keywords: biodiesel; camelina sativa biodiesel; engine emissions

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1. Introduction

It is essential that the entire nation focuses on evolving and developing their society constantly in everyday life. To do this, the energy requirements for achieving the needs of technical developments must be met. As new energy-harvesting systems are created, they will have the ability to alter the conditions of civilization [1]. Petroleum-based fuels have been used as a significant source of energy, but as the world's population is expected to increase over the next century, it is anticipated that the availability of fossil fuels like these will decrease. During combustion, these fuels may release damaging toxins and substances. Over the past 30 years, attitudes on the detrimental effects of fossil fuels on ecosystems and temperatures have undergone a shift. As a result, attention has been placed on potential solutions, including plant-based energy, unconventional energy sources like solar and tidal energy, and more. Future fuel options should be more environmentally responsible while remaining commercially viable compared to existing fuels [2,3].

The growing interest in biodiesel is a result of the increasing need for fuel that ignites more cleanly and is compatible with the majority of present-day diesel cars. Unlike diesel fuel with a petroleum base, biodiesel is made from renewable carbon-based sources. The two fuels differ significantly in terms of their chemical, physical, and emission contents and properties, even though they have roughly the same amount of stored energy. Biomass

energy, specifically biodiesel made from used cooking oil, is becoming more popular due to regulations promoting sustainable development and reductions in environmental pollution. Utilizing food waste or food processing waste, particularly waste edible oils, is an attractive option for energy production based on bioresource sustainability, conservational protection, and financial considerations. When used for energy production, used cooking oil is a renewable energy source that does not increase atmospheric carbon dioxide concentrations, unlike fossil fuels. When food waste is used directly as fuel in combustion utilities like internal combustion engines, it produces less ecological pollution and poses fewer wellbeing risks than those associated with fossil fuels because it contains very low levels of sulfur and nitrogen [4].

There are several different types of hydrocarbons in diesel fuel, most of which have carbon numbers between 12 and 22. They consist of aromatics, naphthenes, olefins, and paraffins. The majority of edible oils, including vegetable oil and animal fats, are composed of triglycerides, especially glycerides, which are produced from glycerol and higher fatty acids with carbon numbers C12 to C22, including lauric, myristic, palmitic, stearic, oleic, linolenic, and linoleic acids. A caustic catalyst is used to react triglycerides and alcohol to create glycerol and oxoalkyl esters, which can then be used to make biodiesel [4]. In compression ignition engines, biodiesel has the potential to replace diesel fuel and is seen as a clean energy source. Without any separation, biodiesel can be mixed with conventional petroleum-based fuel [5,6]. Based on the literature, very little work has reported on the use of camelina sativa oil in the preparation of biodiesel and experiments with it in engines. Hence, in this investigation, the usefulness of camelina sativa oil as a biofuel to run a DI diesel engine is studied.

2. Materials and Methods

The materials for our preparation of biodiesel were procured from a well-known source in Chennai. Neat camelina sativa L. oil, which is pale brown in color, is viscous in nature and thus cannot be used as such in a DI Diesel engine. The highly viscous oil may lead to clogging of the filter and injectors. So, the oil needs to be transesterified to reduce its viscosity. The oil must be processed to lower the free fatty acid (FFA) concentration since a greater acid value might trigger a saponification reaction. The esterification process was first used to reduce the FFA. In this procedure, camelina sativa L. oil was added to react with methanol while being exposed to H_2SO_4 as an acid catalyst. This procedure was kept at a temperature of 65 °C for 120 min while being stirred at a velocity of 400 rpm.

The product was allowed to set for 24 hours in a separating funnel. The product was then transferred to a container and the acid value was checked again, and we found that it was less than 2%, meaning that the transesterification process could be performed. In a 200 mL flask with a magnetic stirrer, a reflux condenser, and a thermometer, transesterification was carried out. NaOH was dissolved in methanol and combined with the oil in a separate conical flask, which was kept at a temperature of 65 °C. This process was maintained similarly at a temperature of 65 °C, and stirred at a rate of 350 RPM for a duration of 60 min. The byproduct glycerin was separated after 24 h with a separating funnel. The physiochemical properties of the Fatty Acid Methyl Esther (FAME) are tested and presented in Tables 1 and 2.

Table 1. Fatty acid composition of neat camelina sativa oil.

Fatty Acids	Carbon Atoms	Relative %
Myristic ($C_{14}H_{28}O_2$)	14:0	0.18
Palmitic ($C_{16}H_{32}O_2$)	16:0	29.68
Stearic ($C_{18}H_{36}O_2$)	18:0	6.23
Palmitoleic ($C_{16}H_{30}O_2$)	16:1	0.73

Table 1. *Cont.*

Fatty Acids	Carbon Atoms	Relative %
Oleic ($C_{18}H_{34}O_2$)	18:1	32.31
Linoleic ($C_{18}H_{32}O_2$)	18:2	7.34

Table 2. Biodiesel properties of camelina sativa biodiesel.

Property	Biodiesel Fuel Standard	Diesel Fuel	Camelina Sativa Oil	Camelina Sativa Oil Methyl Ester
Density	0.86–0.90	0.834	0.901	0.880
Kinematic Viscosity	1.9–6.0	1.9–4.1	18.08	4.31
Cloud Point	−3.0 to 12	−15 to 5		2
Pour Point	−15 to 16	−35 to −15		−3
Flash Point	100–170	60–80	120	162
Sulfur Content	0.05	0.05	ND	ND
Calorific Value				38,500

2.1. Methodology

The biodiesel produced is blended with diesel oil on a volume basis in various proportions. These blends were prepared just prior to conducting the test in the engine.

1. CMB—10% camelina sativa L. biodiesel + 90% diesel
2. CMB—20% camelina sativa L. biodiesel + 80% diesel
3. CMB—30% camelina sativa L. biodiesel + 70% diesel
4. CMB—40% camelina sativa L. biodiesel + 60% diesel

After inspecting all of the basic requirements for running an engine, such as the quantity of lube oil, coolant water flow, etc., the apparatus was initially run with diesel for a while to obtain stable conditions. Once the engine attained a stable condition, the no load readings were taken. A stopwatch was used to measure and record the time it takes to consume 10 cc of gasoline. This trial was repeated three times and the average value was recorded for calculations. The combustion data as well as other performance data were simultaneously recorded utilizing the data collecting equipment. An AVL five-gas analyzer was used to capture the emission data. Once this process was completed, the engine was loaded with 25%, 50%, 75%, and 100% load and the same procedure was followed to capture the data. This test was used as a baseline test for comparison between the CMB biodiesel blends. The engine was operated using the prepared biodiesel blends and the readings were recorded accordingly. The engine was built to operate on diesel in between two blends in order to clear the extra biodiesel blends from the fuel line and filters.

2.2. Working Setup

A single-cylinder, four-stroke, dynamically inhaled, water-cooled diesel engine was employed for the experiments in this investigation, as shown in Figure 1. An eddy current dynamometer was used to load the engine. The emissions were measured using an AVL five-gas analyzer. A stopwatch was used to measure fuel use. The engine's specifications were as follows: four-stroke diesel engine with a single cylinder; loading type: eddy current dynamometer; bore size: 87.5 mm; stroke length: 110 mm; displacement: 661 cc; speed: 1500 rpm; maximum power: 5 hp; ratio of compression: 17.5; timing of injection: 23°BTDC; pressure for injection: 200 Kg/cm^2.

Figure 1. Diesel engine setup.

3. Results and Discussion

The test was conducted with various testing parameters and was consolidated as shown below.

3.1. Analysis of Cylinder Pressure vs. Crank Angle

The in-cylinder pressure in relation to the crank angle is shown in Figure 2. The graphic makes it clearly apparent that the peak pressure increases as the applied load increases. This is due to the fact that as the load expands, more fuel is injected. The graph shows that the peak pressures for the different camelina biodiesel blends are almost identical [7], whereas the diesel shows a higher peak pressure due to its higher calorific value. For the blend CMB 20, the maximum peak pressure obtained was 71.24 Bar.

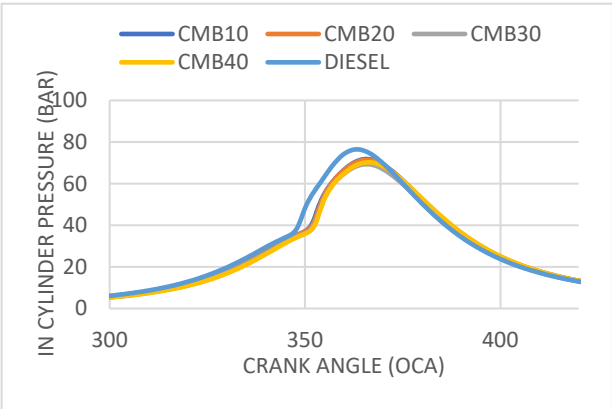

Figure 2. Effects of in-cylinder pressure with respect to the crank angle.

3.2. Effects of Heat Exhaust with Varying Crack Angles

The heat release rates for the different mixes of camelina biodiesel and diesel are shown in Figure 3. The fuel's energy availability is indicated by the heat release rate. From the graph, it is clear that the diesel recorded the higher heat release rate. which is followed by the camelina sativa biodiesel blends [8]. The reason for the lower HRR of the biodiesel may be due to its lesser calorific value when compared to the diesel. Among the various biodiesel blends, CMB 20 gives the highest biodiesel blend heat release rate of 28 joules, which is in accordance with the in-cylinder pressure.

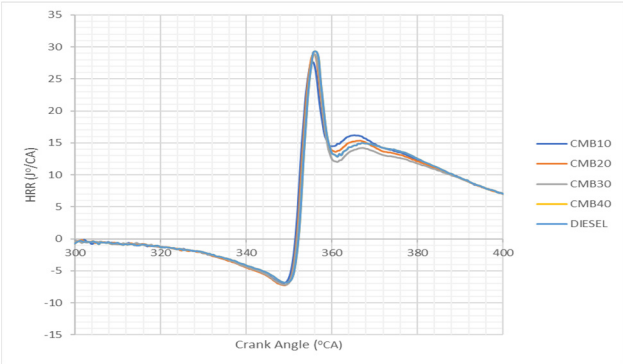

Figure 3. Effects of heat release with respect to the crank angle.

3.3. Effects of Different Fuels on the Brake Thermal Efficiency

The brake thermal efficiency (BTE) of various mixes of camelina biodiesel and diesel is shown in Figure 4. The engine's thermal efficiency varies depending on the engine load, as seen by the brake thermal efficiency graph. The BTE is a percentage indicating how much of the fuel's energy is used to produce useful work. This graph offers important details about the engine's capacity to transform fuel energy into productive work. Better fuel efficiency and overall engine performance are indicated by improved brake thermal efficiency [9]. Among the various biodiesel blends, CMB 20 exhibited higher efficiency rates than the other blends and was sightly similar to diesel. CMB 20's peak value point in the graph is at 23.458%.

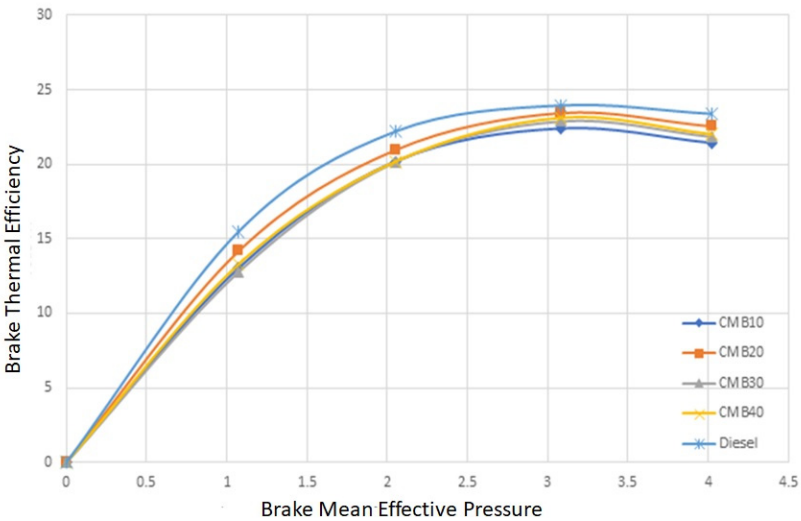

Figure 4. BTE vs. brake mean effective pressure.

3.4. Effects of Fuel Consumption

The specific fuel consumption (SFC) for various mixes of camelina biodiesel and diesel is shown in Figure 5. This particular fuel consumption graph illustrates that fuel consumption per unit of power output varies with engine load. This graph offers important details about the engine's fuel efficiency under various loads. A higher fuel economy and reduced running expenses are shown with a lower specific fuel consumption. Engines operating at their optimal conditions, such as the right air–fuel ratio, can result in more complete combustion, higher engine efficiency, and lower SFC values [10,11]. Diesel and CMB 20 showed decreased fuel consumption rates at 0.389 kW/kg hr and 0.355 kW/kg hr, respectively.

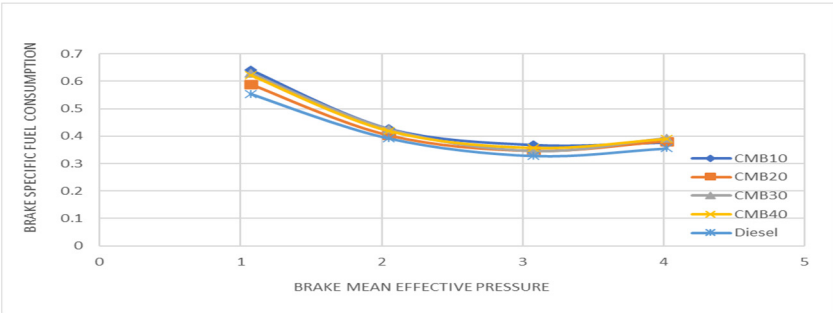

Figure 5. Effects of varying fuel conditions on specific fuel consumption.

3.5. Carbon Monoxide vs. Brake Mean Effective Pressure

The carbon monoxide (CO) emissions of different mixes of camelina biodiesel and diesel are illustrated in Figure 6. The quantities of carbon monoxide (CO) emitted from the engine across various load circumstances are displayed in the CO emissions graph. Incomplete fuel combustion results in the production of CO. The fuel does not burn entirely when there is not enough oxygen in the combustion chamber, which results in the generation of CO. Insufficient air–fuel mixing, a low combustion chamber temperature, and other variables can result in incomplete combustion in engines and significant CO emissions. According to our graph, different biodiesel mixes create exhaust emissions with less carbon monoxide (CO) than diesel [12]. CMB 10, 20, 30, and 40 produce less CO emissions compared to conventional diesel due to their oxygen contents. When compared to diesel, biodiesel has a higher oxygen content, which encourages a more thorough burning and reduces CO emissions. Furthermore, biodiesel has lower concentrations of sulfur and aromatic chemicals, which also help to cut CO emissions.

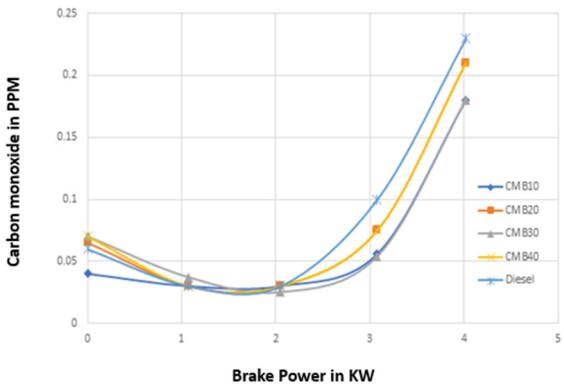

Figure 6. Brake power vs. carbon monoxide in (PPM).

3.6. Nitrous Oxide Emission Rates

The NOx emissions of different camelina biodiesel and diesel mixes are displayed in Figure 7. The nitrous oxide (NO) and nitrogen dioxide (NO_2) gases that are created during combustion processes are represented collectively in these test results. These emissions are a result of the air's nitrogen and oxygen reacting at a high temperature during combustion. NOx emissions are a significant source of air pollution and can have a bad effect on the environment and human health. The graph shows that, when compared to diesel fuel, the NOx emissions for the CMB 20 and CMB 10 fuels were found to be similar, with values of 524 and 515, respectively. High temperatures, N, and O_2 are all necessary for NOx generation, and the amount of NOx generated grows as O_2 concentrations rise. Because our biodiesel blends include more oxygen than conventional diesel fuel, there are more combustion zones and more fuel-rich zones, which results in higher NOx emissions. Additionally, the SFC of the biodiesel blends was found to be greater than that of the diesel fuel, which further contributes to the creation of NOx emissions. This, in turn, leads to

a rise in the number of zones with high ambient temperatures, which in turn causes an increase in NOx generation [13,14].

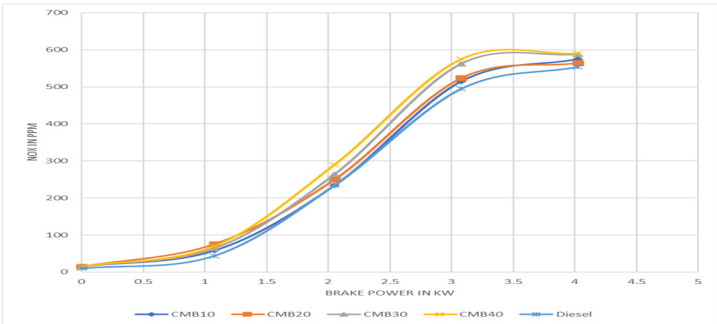

Figure 7. NOx emissions.

3.7. Hydrocarbons vs. Brake Mean Effective Pressure

Figure 8 shows the hydrocarbon (HC) emissions of various biodiesel and diesel mixes made from camelina sativa. Due to the fact that biodiesel has a greater oxygen content than diesel fuel, which increases the combustion efficiency and lowers the amount of unburned fuel, the HC (hydrocarbon) emissions are often lower for biodiesel blends than for diesel fuel. The graph shows that the HC values of the CMB 20 fuel were discovered to be lower than the other fuel blends and that its values were comparable to those of diesel. The oxygen content of this biodiesel is what caused a drop in its HC emissions. The kind of engine used also affects these emission values. Additionally, one of the elements contributing to higher HC emissions is thought to be an engine's high compression ratio [15].

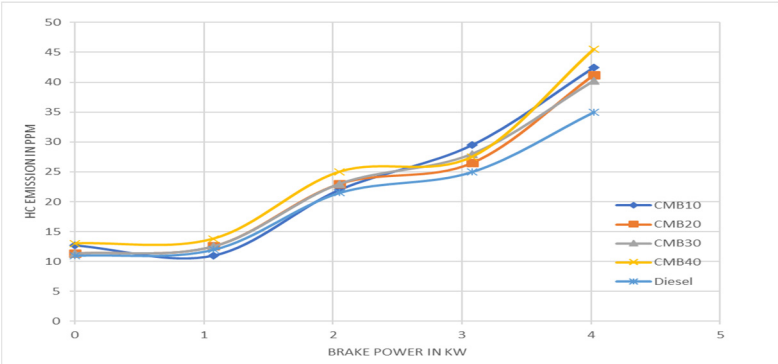

Figure 8. HC emissions.

4. Conclusions

In this study, camelina sativa oil was used for the preparation of biodiesel, and recorded a yield of 95.9%. The biodiesel produced was tested for its physical and chemical properties and found to be in accordance with ASTM standards. The biodiesel was then blended with diesel at various proportions and tested in a DI diesel engine. The output was recorded and analyzed. We following results as follows:

1. The engine's performance was aided by the lower cylinder pressure and heat release rates of the biodiesel compared to diesel alone.
2. The CMB 20 fuel's brake thermal efficiency is somewhat comparable to diesel. This may result in increased fuel efficiency, decreased emissions, and lower operating expenses.
3. The specific fuel consumption of CMB 20 and diesel is similar, which lowers the engine's operating costs, while also raising fuel efficiency.
4. Regarding the CO, NOx, and HC emission characteristics, CMB 20 performs better than other mixes and emits fewer pollutants than diesel.

The results revealed that the CMB 20 mix (80% diesel and 20% camelina biodiesel) performed better and had fewer emissions than other blends. CMB 20 is favored as a substitute for petroleum-based diesel since it may be used in diesel engines directly without requiring any engine changes.

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