Impact of Biodiesel Blends on Exhaust Emissions of a Compression Ignition Engine

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***Abstract*—The increasing global consumption of petroleum fuels, coupled with limitations in their extraction, has resulted in a noticeable rise in fuel prices. At the same time, growing concern about environmental pollution has restricted their continued use, creating the need for a sustainable alternative fuel that can offer an effective solution. Biodiesel has emerged as one of the most widely explored alternatives. However, biodiesel production from conventional oil seeds is constrained by the issue of crop land displacement. In this regard, biodiesel derived from algae presents a promising option, as it can be cultivated in ponds without competing for agricultural land and offers a higher yield compared to oil seeds.**

The present work focuses on evaluating the performance of a diesel engine using algae oil as fuel. To enable its use in the engine, blends of algae oil with petroleum diesel were prepared. The properties of algae oil and its blends were tested and compared with those of neat diesel. The results indicate that the properties of algae oil and its blends are very similar to those of diesel fuel. Additionally, the calorific values of the blends were found to be close to that of neat diesel, supporting their suitability for engine applications.

The prepared blends were tested on a variable compression ratio diesel engine to study their performance characteristics. The results show a slight reduction in torque, brake power, and brake thermal efficiency, along with a marginal increase in specific fuel consumption as the blending ratio increases. Emission analysis revealed a reduction in CO, CO_2, and HC emissions, with a slight increase in NOx emissions. Among the tested blends, B10 demonstrated the most favorable overall performance. It can be concluded that algae biodiesel can be blended with diesel up to 20% and used in a diesel engine without requiring any modifications.

***Index Terms*—Algae, Biodiesel, Emissions.**

I. INTRODUCTION

India is one of the fastest growing markets in the world. The economic growth of the country is driving energy consumption across all major sectors. It makes India fourth largest primary energy and petroleum consumer [7]. As the country has limited resources, it makes us think of an indigenous source. Biodiesel, from long ago, is being studied as a promising alternative.

India, being an agrarian nation, has adequate resources to produce biodiesel from both edible and non-edible oil seeds. However, concerns related to food security limit the use of edible oils, encouraging the use of only non-edible sources for biodiesel production. Oils such as jatropha, rapeseed, soybean, palm, and sunflower are commonly utilized for this purpose, and animal fats can also serve as suitable feedstock.

Although oil seeds are a reliable source for biodiesel production, their cultivation is associated with the issue of crop land displacement. The land required for growing these oil crops is often the same land previously used for cultivating edible crops. As a result, the overall land available for food production may decrease, leading to reduced edible oil output and a rise in prices. In this context, biodiesel production from microalgae offers a comprehensive solution. Since microalgae can be cultivated in ponds or bioreactors without occupying agricultural land, the problem of crop land displacement can be avoided. Additionally, microalgae provide a higher oil yield compared to conventional oil seeds, making them a promising alternative feedstock for biodiesel production.

II. ALGAE BIODIESEL

Algae are unicellular or multicellular photosynthetic organisms that do not possess typical plant structures such as leaves, roots, seeds, or flowers. They are commonly found in aquatic environments, including both freshwater and marine systems. Microalgae can be cultivated in open systems such as ponds, lakes, and raceways, as well as in controlled closed systems like photo bioreactors, similar to those used in commercial fermentation. The photosynthetic growth of microalga biomass requires light, carbon dioxide, water, nutrients, and a temperature range of about 20–30 °C. Open cultivation systems are more economical due to their lower operational cost; however, biomass productivity in such systems is limited. To achieve higher yields, closed cultivation systems are preferred.

Algal oil is stored within the cells and is associated with proteins and various carbohydrates such as starch, cellulose, hemicellulose, and pectin. These cellular components are enclosed by a relatively thick cell wall that must be disrupted to release the oil and proteins. Several methods are available for extracting algal oil, including mechanical extraction using hydraulic or screw presses, enzymatic methods, chemical extraction using organic solvents, ultrasonic extraction, and supercritical carbon dioxide extraction.

Biodiesel can be produced by transesterification of algal oil. Transesterification is the reversible reaction of fat or oil (which is composed of triglyceride) with an alcohol to form fatty acid alkyl ester and glycerol. The reaction occurs stepwise: triglycerides are first converted to diglycerides, then to monoglycerides and finally to glycerol [18].

Microalgae are capable of synthesizing more oil per acre than the terrestrial plants as they can double their biomass within 24 hours [19]. Hence using microalgae to produce biodiesel will not compromise production of food, fodder and other products derived from crops.

III. EXPERIMENTAL SETUP

In the present study, the performance of various diesel–biodiesel blends was evaluated using a diesel engine. For this investigation, blends of petroleum diesel and algae biodiesel were prepared and designated as B00, B10, B20, and B30. B00 represents neat diesel and serves as the reference fuel for comparison. The blends B10, B20, and B30 consist of 10%, 20%, and 30% algae biodiesel mixed with diesel by volume, respectively.

The experiments were conducted on a Kirloskar single-cylinder diesel engine. A hydraulic dynamometer was employed to apply load to the engine output shaft. A data acquisition system was used to record various engine parameters, and a five-gas analyzer was utilized to measure the exhaust emissions.

Table 1: Engine Specifications

Engine Make	Kirloskar TV1 VCR
Number of Cylinders	1
Cycle	4 Stroke
Rated Power	3.5 KW @ 1500 rpm
Cylinder Diameter	87.5 mm
Stroke Length	110 mm
Connecting Rod Length	234 mm
Compression Ratio	12 to 18
Cooling Medium	Water Cooling

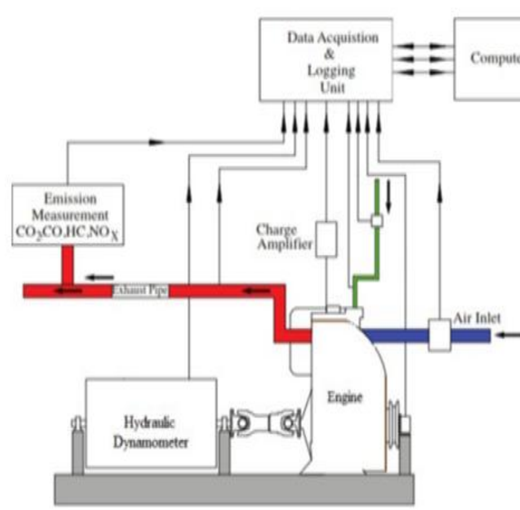

Fig1: Experimental Setup

IV. RESULTS AND DISCUSSION

A. Density

Density is the measure of mass per unit volume of a material. Biodiesels, in general, are characterized by higher densities than conventional petroleum diesel. This means, volumetrically operating fuel pumps will inject greater mass of fuel. This will affect the air fuel ratio of the engine [14].In present study, density of biodiesel blends is found to be increasing with the increase in blend ratio.

B. Viscosity

It is a measure of internal resistance to flow of a fluid. Higher viscosity of fuel enhances fuel spray penetration and thus improves air fuel mixing [38]. However, fuel with higher viscosities cannot be used safely in compression ignition engines [14]. It is seen that the viscosity of the blend increases with increase in blending ratio. This limits the blending ratio of diesel and biodiesel.

C. Calorific Value

Calorific value is the measure of heat content of fluid or fuel. It is very well established that, calorific value of biodiesel is lower than petroleum diesel. The same is observed in the study. This also reduces the calorific value of biodiesel blends. This, in turn, means that more fuel will have to be consumed for getting the same work output from an engine which is using petroleum diesel. This will increase the specific heat consumption and may lower the torque and power output of the engine.

D. Cetane Number

Cetane number is one of the most important characteristics of fuel. It is a dimensionless number and indicates the ignitability of the fuel [14]. Higher cetane number of fuel promotes faster auto ignition of fuel and reduces the emissions of nitrogen oxides [14]. Cetane number of biodiesel blends in present study is found to be higher than diesel, which creates a possibility of better combustion and knock free working of the engine.

V. EXHAUST EMISSIONS

Engine trails were conducted at different loads and different compression ratios. At these conditions the exhaust emissions were measured. The result is as tabulated below. In the present work, four major emissions are considered viz. CO, CO2, HC and NO. Study shows a minor decrease in emissions of CO and HC for lower loads. At higher loads emissions of HC are almost similar to that of diesel. B20 blend shows better results for emissions of CO and HC. Emissions of nitrogen oxides are increased with increase in blend ratio. This may be due to improved atomization of biodiesel blends and higher temperatures.

A. Carbon Monoxide and Carbon Dioxide(CO, CO2)

Carbon monoxide is colorless, odorless poisonous gas. It is generated when the engine is operated with fuel rich mixture. It is indicative of incomplete combustion. The study shows a decrease in emissions of carbon monoxide and carbon dioxide for all blends and all loading conditions. The emissions are slightly more for all the blends at lower compression ratio and lower load. Graph below shows the carbon monoxide and dioxides at 100% load and compression ratio of 17.

B. Hydrocarbon (HC)

Hydrocarbon emissions depend on combustion efficiency of the engine. Some fuel particles may condense on the surface of soot. Diesel engines have higher HC emissions. However, it can be observed that hydrocarbon emissions reduce with increasing load. The study shows minimum hydrocarbon emissions at 100% load and compression ratio of 17.5. Also for all other loading conditions, biodiesel blends show decrease in HC emissions. The graph below shows HC emissions at 100% load and compression ratio of 17.

C. Nitrogen Oxides (NOx)

It is created mostly from nitrogen in the air. The reaction takes place at higher temperatures. In addition to this, formation of NOx also depends on availability of excess oxygen. Because of this emission of NOx increase in biodiesel blends as compared to straight diesel. It is observed that emissions of NOx increased for all blends and all loading conditions. Also, it can be observed that emissions of NOx increase with increase in blending ratio. The graph below shows the comparison of NOx emissions at 100% load and compression ratio of 17.

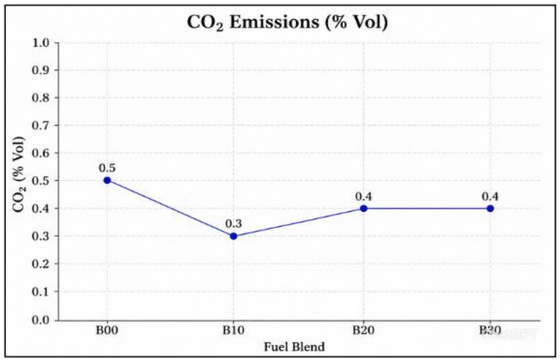

Fig 2: Comparison of CO_2 Emissions (100% Load)

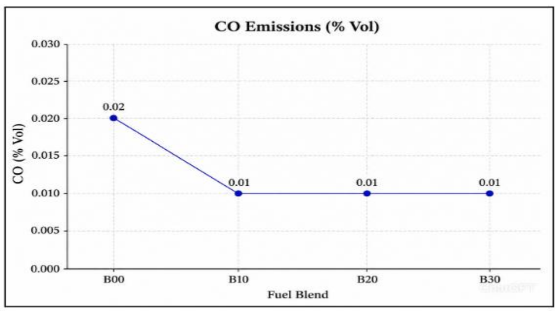

Fig 3: Comparison of CO Emissions (100% Load)

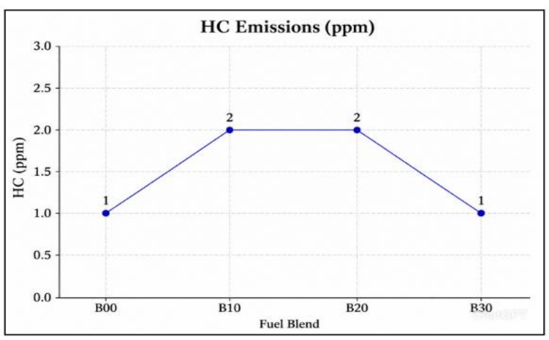

Fig 4: Comparison of HC Emissions (100% Load)

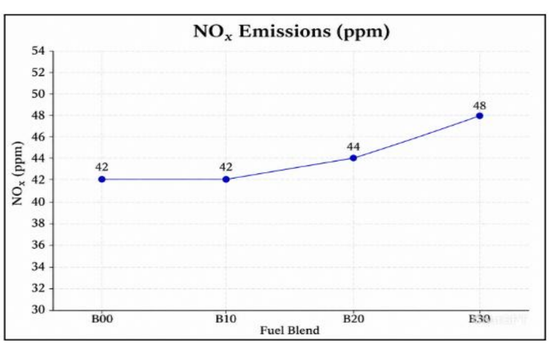

Fig 5: Comparison of NO_x Emissions (100% Load)

VI. CONCLUSION

To use with diesel, the blends of straight diesel and algae biodiesel were prepared. The physiochemical properties of these blends were tested. It is found that:

a. The density of the blend increases with the blending ratio.
b. Due to higher viscosity of algae biodiesel, the viscosity of the blend also increases with increase in blending ratio.
c. Algae biodiesel possesses lower calorific value than straight diesel. Because of which, calorific value of biodiesel blends also decreases with increase in blending ratio.
d. However, as cetane number of algae biodiesels is more than straight diesel. The cetane number of biodiesel blends improves with increase in blending ratio.

The blends of biodiesel were tested in a diesel engine. The study shows that:

a. The emissions of carbon monoxide decrease with the use of biodiesel as compared to straight diesel.
b. The emissions of carbon dioxide also decreased with use of biodiesel with the straight diesel.
c. The blending of biodiesel with diesel has minimal effect on emissions of hydrocarbons.
d. The emissions of nitrogen oxides, however, increased with increase in blending ratio.
e. All the blends show better performance at higher load and higher compression ratio.

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