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Research Article

Study of Performance and Emission in a Diesel Engine using Emulsified Chlorella Algae Oil

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ABSTRACT

Petroleum-based fuels play a vital role in rapid depletion of conventional energy sources along with increasing demand and also major contributors of air pollutants. Major portion of today's energy demand in India is being met with fossil fuels. Hence, it is high time that alternate fuels for engines should be derived from indigenous sources. Many alternate fuels such as alcohols, biodiesel, methanol, ethanol, LPG, and CNG have been already commercialized in the transport sector. The main sources of renewable energy are biomass, biogas, methanol, ethanol, and biodiesel. The microalgae oil is used as the biofuel in the direct injection diesel engine. The oil extracted from algae by pyrolysis process. Blend diesel 90% with *Chlorella* algae oil 10% and the emulsion of tween-80 mixture 2%. An experimental investigation carried out to analyze the effect of diesel-biofuel blended fuels on the engine performance and emission such as specific fuel consumption, brake thermal efficiency, calorific value, CO, NOx, and HC. The experiments were conducted on a single cylinder four-stroke diesel engine fuelled with diesel, diesel with biofuel, and diesel-biofuel-Tween80 blends at varying load. The performance and emission results of the emulsified fuel and diesel were compared, the performance results show the emulsified fuel almost closer to the diesel, and the emulsified fuel emission is less than to the diesel.

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INTRODUCTION

Diesel engines are mainly used in industrial, transport, and agricultural application due to their high efficiency and reliability. However, they suffer from high smoke and oxide of nitrogen emissions. The increase in prices of diesel fuel, reduced availability, more stringent government regulations on the exhaust emissions, and the fast depletion of worldwide petroleum reserves provides a strong encouragement to the search for alternative fuels. Among the different type non-renewable alternate energy resources, biomass is an energy resource which has promising characteristics to use as fuel in diesel engine. Hence, an attempt was made in this work to investigate the efficient techniques to utilize algae oil as fuel in diesel engine. Many alternative fuels for diesel engines such as vegetable oil esters, tyre pyrolysis oil, and orange oil were introduced from the recent researches. Depletion of petroleum derivatives and increase in emission in diesel engine increase the research interest in the area of alternative fuels. The heat volatilizes and decomposes the organic matter to produce a pyrolysis gas and liquid and solid char in relative proportions depending on the process parameters of temperature and pressure, the performance and emission characteristics were found and compared with diesel.

MICROALGAE

Microalgae are currently the most promising source of biofuels for total substitution of fossil fuels.[1] Distinct benefits of microalgae compared to terrestrial feedstock include, but are not limited to, their higher photosynthetic efficiencies, and higher productivity which can potentially produce substantially greater biomass yields per day and per unit cropping area. The numbers of studies that have evaluated the potential of using raw algal oil in an engine are insufficient to gain a full understanding of the likely performance of this fuel. The use of raw algal oil can overcome problems related with the use of expensive chemicals and procedures during the transesterification reaction necessary to produce biodiesel [Table 1].

Chlorella

Chlorella is a genus of single-cell green algae belonging to the phylum chlorophyta. It is spherical in shape, about 2–10 μm in diameter, and is without flagella. *Chlorella* contains the green photosynthetic pigments chlorophyll-a and -b in its chloroplast.

Microalgae can also grow in extreme environments; it could be produced on agricultural and non-agricultural lands.

It could also make use of fresh, brackish, saline, wastewater, municipal sewage, and industrial effluents. Many microalgae species are able to switch from phototrophic to heterotrophic growth conditions [Figure 1].[2]

Advantages of algae as a fuel

1. In recent years, algae have become more attractive as alternative fuel sources because they provide several advantages compared with terrestrial plants. Algae are mostly non-food crops; therefore, they will not compete with other uses in the market, unlike other biofuel feedstocks such as corn, palm, and peanuts. Algae would use over 3 times less farming area than corn, canola, and switchgrass to meet the annual US energy consumption.
2. Algae grow faster than most seed crops, and the energy produced per hectare from algae can be 30–100 times greater than land crops.
3. In addition, algae can help reduce impacts from agricultural activities related to chemical uses such as fertilizers and pesticides. Comparing the life-cycle impacts of biodiesel from various feedstocks including algae, rapeseed, soybean, and palm, algae biodiesel showed the lowest impacts on eutrophication and land use because of smaller amounts of pesticides and fertilizers used.
4. Algae can also grow in marine water, freshwater, or even in wastewater treatment ponds. It was found that green algae could grow well on wastewater collected from four different types of treatment units at a wastewater treatment plant. In addition, the algae removed up to 80% and 90% of total nitrogen and phosphorus, respectively, from the wastewater.
5. Most research has focused on microalgae, due to its faster growth rate, productivity, and higher lipid content.

EXTRACTION PROCESS

Pyrolysis process

Pyrolysis is a thermochemical decomposition process in which organic material is converted into a carbon-rich solid and volatile matter by heating in the absence of oxygen [Figure 2].

Working method

The reactor is placed on the floor with temperature indicator. The outlet of the reactor is directly connected to the condenser using a stainless steel tube which can withstand high temperature. Another one inlet is connected to the reactor from the nitrogen cylinder. The condenser is firmly connected with the help of alloy gasket. Counterflow condenser here selected. The flow of water is directed against the direction of pyrolysis gases. The condensate drips into the gas-liquid separator. The non-condensable gases rise to the neck of other tube and pass through the exhaust tube to gas burner. To measure the temperature outside the reactor, the thermocouple is connected to the digital temperature indicator. Using setup button set the temperature level. The setup reaches that temperature automatically off the supply. The temperature reduces the temperature of automatically power on.

Table 1: Different types of microalgae

Microalgae	Oil content (% of dry weight
Botryococcus braunii	25–75
Chlorella sp.	28–32
Nannochloris sp.	20–25
Isochrysis sp.	25–33
Nannochloropsis	31–68
Spirulina sp.	14–20
Scenedesmus sp.	30–45
Cyclotella	35–42
Tetraselmis	15–32

Figure 1: *Chlorella* biomass

Figure 2: Photographic view of engine setup

In this pyrolysis setup, algae biomass is filled the reactor initially and then closed the reactor with the help of bolt. Here, gasket was used to prevent leakage. Then, supply nitrogen gas from the cylinder to reactor the time period of 3–4 min supplied, after that it will be closed. Switch on the supply, initially set the temperature up to 350°C in the temperature controller. Condenser water is supplied from inlet to outlet.

Gases are collected in the balloon. Finally, note the time taken to reach the temperature up to 350°C. Cooling time of the reactor is 16–18 h. Finally, we have collected the pyrolysis oil, char, and gases [Figure 3].

Blending of *Chlorella* oil and diesel with Tween 80

Emulsified biofuel is prepared using magnetic stirrer with the hot plate as shown in Figure 4. The main objective is to evaluate the long-term stability of three phases with respect to Tween 80.[3] Emulsified biofuel was produced with a combination of 2% Tween 80 with 10% *Chlorella* oil and 90% diesel (CL10D90E2) using magnetic stirrer machine [Table 2].[4]

EXPERIMENTAL ANALYSIS

A single cylinder, four strokes, naturally aspirated, air-cooled diesel engine of 4.4 kW power output is used for this experiment. This engine is used to conduct the entire analysis of the project. The cooling method is providing water jacket around the heat transfer surface, and continuous flow of air is there. This arrangement ensures that there is no temperature raise inside the engine in all varying loads.

Specifications

Single cylinder, vertical, air-cooled, four-stroke diesel engine.

Make: KIRLOSKAR
Bore: 87.5 mm
Stroke: 110 mm
Cubic capacity: 1323 cc
Speed: 1500 rpm
Power: 5HP/3.7 kW
Compression ratio: 16:1
Type of loading: Electrical loading

The setup consists of a single cylinder, four strokes, naturally aspirated, water-cooled diesel engine connected to Eddy current dynamometer. This Eddy current dynamometer is used for loading the engine. The engine is interfaced with Engine Soft Software for the measurement of combustion parameters. It is provided with necessary instruments for combustion chamber pressure and crank-angle measurements. For the measurement of cylinder pressure, a pressure transducer is fitted on the engine cylinder head and a crank angle encoder is used for the measurement of crank angle and TDC position [Figure 5].

The pressure and crank angle signals are fed to a data acquisition card fitted with Pentium 4PC. The engine speed is sensed and indicated by an inductive pickup sensor in conjunction with a digital rpm indicator, and this is a part of Eddy current dynamometer.

The liquid fuel flow rate is measured on the volumetric basis by a transmitter. Provision is also made for interfacing airflow, temperatures, and load measurement. The airflow is measured using an orifice meter, and the exhaust gas temperatures are recorded with thermocouples.

The setup has stand-alone panel box consisting of air box, fuel tank, manometer, and fuel measuring transmitter. Rotameters are provided for cooling water and calorimeter water flow measurement. The various components of experimental setup are shown in Figure 5.

RESULTS AND DISCUSSION

Brake power with brake thermal efficiency

The performance of different load for biofuel CL10D90, emulsified biofuel CL10D90, and diesel is shown in Figure 6, when load increases the efficiency of both biofuel and diesel increase.[5] The brake thermal efficiency of emulsified biofuel CL10D90 is less than diesel, it is because of lower calorific

Figure 3: *Chlorella* bio-oil

Figure 4: Magnetic stirrer

Table 2: Comparison of diesel with emulsified oil

Property	Diesel	CL10D90	CL10D90E2
Density (kg/m^3)	860	872	891.8
Calorific value (kJ/kg)	43500	42037	40800
Flashpoint (°C)	51	58	63
Fire point (°C)	56	61	67
Viscosity (cP)	3.56	4.2	4.37

value and the emulsified biofuel CL10D90 exhibit low thermal efficiency in low load compared to diesel and improvement in higher load, this is because of the micro explosion phenomenon, the air-fuel mixture improves higher combustion efficiency.[6] The brake thermal efficiency of emulsified CL10D90 is almost nearer to the diesel.

Brake power with specific fuel consumption

The specific fuel combustion of emulsified biofuel CL10D90 is higher than diesel, and this is because of lower energy content in the biofuel. The specific fuel consumption of emulsified CL10D90 is 0.4189 kg/kW-h, whereas for diesel fuel, it is 0.355 kg/kW-h at full load [Figure 7].

Brake power with carbon monoxide

There is more oxygen chemically bounded with emulsified biofuel in CL10D90 which is an additional source of oxygen present in the intake of air. It tends to decrement in the emission of carbon monoxide [Figure 8].[7]

Brake power with hydrocarbon

Emulsified biofuel CL10D90 shows the reduction in HC emission due to its efficient burning than diesel. HC emissions of emulsions are found decreasing than the diesel,[8] and this is because the proper air-fuel mixture improves the combustion process [Figure 9].

Brake power with nitrogen oxide

The graph shows that NO_x emission for emulsified biofuel CL10D90 decreases for all the load conditions, and it is observed that the water content present in the emulsified fuel leads to proper air-fuel mixture,better combustion, and less emission of NO_x than diesel [Figure 10].

CONCLUSION

The performance, combustion, and emission characteristics of diesel, biofuel, and emulsified biofuel (diesel - biofuel - tween 80) were investigated on single cylinder four-stroke diesel engine.

Figure 5: Photographic view of engine setup

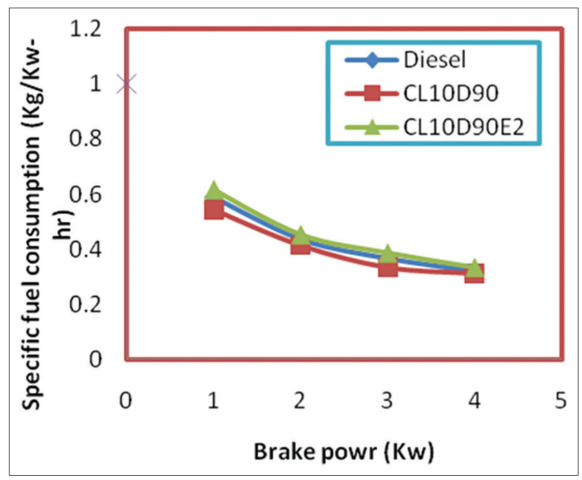

Figure 7: Comparison of brake power with specific fuel consumption

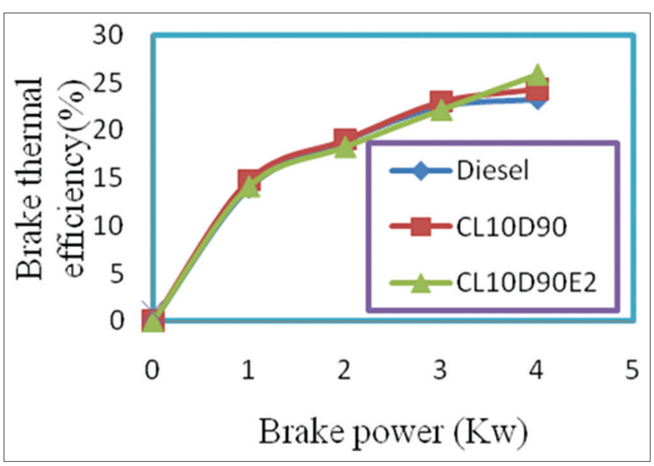

Figure 6: Comparison of brake power with brake thermal efficiency

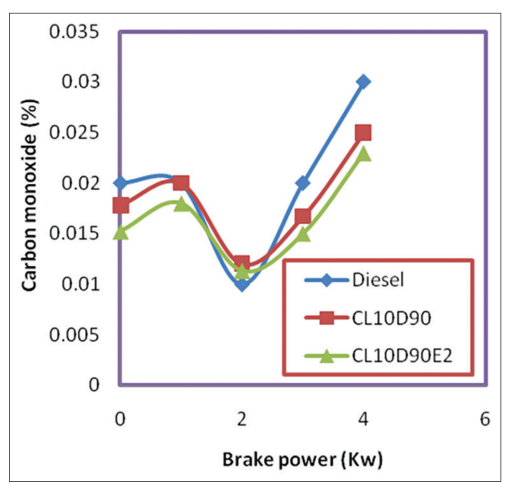

Figure 8: Comparison of brake power with carbon monoxide

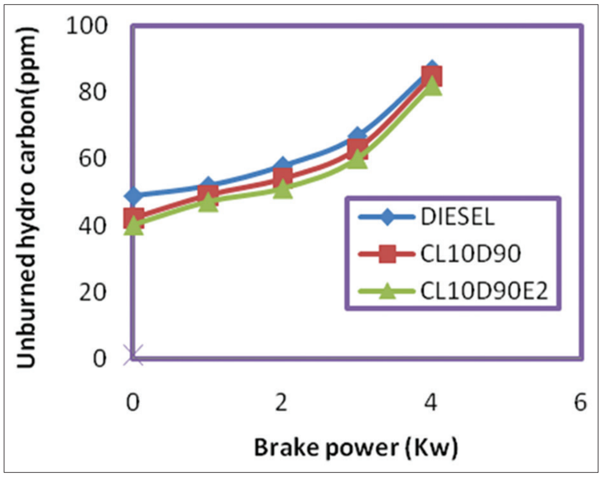

Figure 9: Comparison of brake power with hydrocarbon

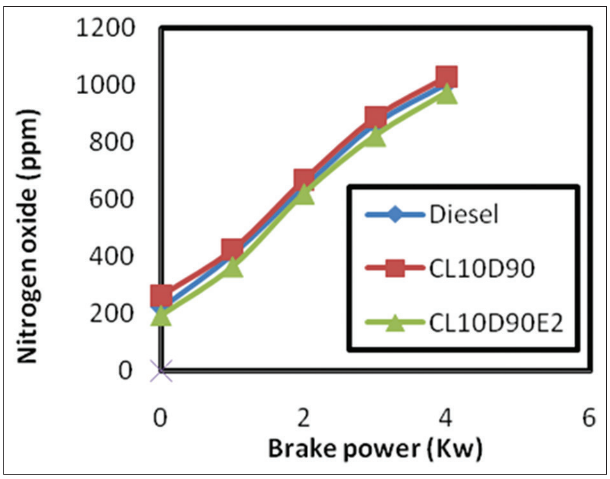

Figure 10: Comparison of brake power with nitrogen oxide

The brake thermal efficiency of diesel is 23.3% and emulsified biofuel is 25.82%. Hence, the brake thermal efficiency of emulsified biofuel is more than the diesel.

The specific fuel consumption of diesel is 0.355 kg/kW-h and emulsified biofuel is 0.4189 kg/kW-h, and hence, the specific fuel consumption of the emulsified biofuel is closer to the diesel.

The emulsified biofuel emissions of carbon monoxide, hydrocarbon, nitrogen oxideare less than the diesel because of the availability of oxygen content in the biofuel[9] which makes the combustion better.

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