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Experimental investigation on constant-speed diesel engine fueled with biofuel mixtures under the effect of fuel injection

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Abstract

The petroleum product has seen a drastic demand in the recent past. Biofuels are the only solution to overcome this power crisis. In the view of sustainable energy development, biodiesel and its additives have become the best options for fossil fuel-based engines. In this work, a biodiesel mix was used to show the possible utilization of different biofuels. An experimental investigation was carried out on a direct-injection constant-speed (Rated speed- 1500 rpm) diesel engine at different injection pressures of 180, 220 and 260 bar with natural aspiration and supercharging modes. The blends of Biodiesel (used cooking oil, with a mix of algae) and diesel fuels are the selected fuel to investigate. At lower injection pressures, brake specific fuel consumption of the engine was low and further lowered with supercharging operation. With the reduction of injection pressures, brake thermal efficiency values are improved, and the same was observed with supercharging. With the rise in injection pressures, NOx emissions increased due to rise in temperature, and unburnt hydrocarbon emissions were slightly increased. The algae biodiesel was used as an additive to increase the stability of biodiesel. The overall observation indicates that a moderate injection pressure of 220 bar is advisable.

1. Introduction

Energy safety has become the primary concern of all countries. The greatest challenge to the energy sector in the approaching periods will be the creation of sustainable sources of energy. Despite it being predicted that fossil fuels will become extremely expensive by 2050, the application of bio-based feed stocks can be an economically competitive alternative for fossil fuels. Biofuels, however, have been hampered by a variety of obstacles such as lack of suitable technology, facilities, availability, etc. for replacement of fuels.

Due to the high brake thermal efficiency of diesel engines compared to gasoline engines, they have become more popular in the transportation and agriculture sector [1]. As a result of the rapid depletion, rising price, uncertainties over the supply of petroleum fuels and the need to clean up the environment, intensive research for alternative fuels has been triggered [2-6]. A lot of research has been conducted into renewable fuels, which are clean-burning and are being investigated as alternative fuels [2].

Nowadays, there are wide varieties of alternative fuels that can be used with the internal-

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combustion engine with little modification. The advantages with these fuels are cleaner burning than with petroleum-derived fuels. Biofuels have gained large scope for utilization in place of diesel; however, the cost is huge requirements of land for harvesting the crops. Algae, which are a naturally available source, can also be used to make biodiesel [1-3].

Biofuels can be an ideal replacement for petroleum-based fossil fuels. There have been progressive investigations throughout the world for the usage of biofuels like ethanol, methanol, biodiesel, etc. The modified form of vegetable oil that is biodiesel has significantly achieved success for replacing diesel to some extent.

Producer gas is a clear burning gas obtained from solid biofuels by converting them into gaseous fuel inside a gasifier. A gasifier is a simple chemical reactor where both physical and chemical reactions take place. Producer gas can be generated from various sources such as bagasse, coir-pith, ground nutshell, sawdust, straw wood chips, etc. From the literature, it is revealed that according to the direction of flow, gasifiers are of three types: up draft, down draft and cross draft [3]

'Biodiesel' is a renewable fuel substitute- the term refers to ethyl or methyl esters that are produced from vegetable oils or animal fats. Many vegetable oils have been in use in different countries as raw materials for biodiesel production owing to their availability [4-6]. Many researchers throughout the world have tested possible use of the biodiesel in compression ignition (CI) engines. The results coming are in support of biofuels, from both the performance point of view and the emission formation tendency [7-20].

The present work was carried out to understand the working of a constant-speed diesel engine when operated on used cooking oil methyl ester (UCME) for which the oil source was peanut oil. The interest in the selection of the present engine is that it is mostly used in the remote places of developing countries for small power development and agricultural applications. The parameter selected for observation in this test was fuel injection pressure, keeping the other engine design parameters constant. The biodiesel was methyl ester of used cooking oil (UCME) with blends of diesel. An emulsifier was used to make different blends of diesel and biodiesel. The blends were observed for stability by adding algae-based biofuel and subsequently analyzed for fuel properties. The idea behind the usage of algae-based fuel is,

(i) To understand the algal source for making biofuel which can be comparable with other vegetable source biodiesel,

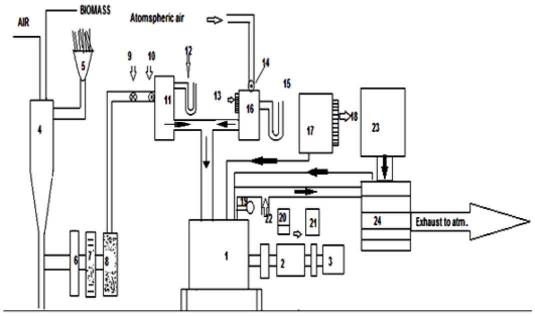
(ii) To mix the available small quantity of algal biodiesel with the other fuels. However, this kind of technique may not give a sound conclusion at this moment, so this can be taken as a trial approach.

2. Experimental setup

A naturally aspirated single-cylinder diesel engine with eddy current dynamometer was selected for experimentation. The supercharging operation was carried out at inlet pressure of 0.5 bar. A two-stage reciprocating compressor was used for supercharging. A surge tank with a valve was provided to maintain uniform inlet air pressure. Digital temperature indicators were used to measure the inlet and exhaust temperatures. A gas analyzer and smoke meter were used to measure the concentrations of exhaust species. The experimental layout of test engine setup is schematically shown in Fig. 1 [1].

The biodiesel blends used for testing are U10, U20, U30, and U100. The pure biodiesel (U100) was obtained from the acid transesterfication of the cooking oil. The catalyst used was NaOH. The quality of biodiesel obtained was good; the blends were prepared using a perfect mixer. The separation of biodiesel and diesel usually takes place because of the miscibility problems of the two different fuels.

So, any additive can be checked here for attaining the uniformity of the blend. Many engine tests are performed soon after preparation of the blends. However, the studies on the stability of blends may give solutions to the storage of fuels. The blends were stabilized with the addition of algae biodiesel (2% by volume).



1. Engine
2. Alternator
3. Electrical resistance loading device
4. Gasifier
5. Burner
6. Cooling unit
7. Passive filter
8. Fine filter
9. Gas control valve
10. Orifice meter
11. Gas surge tank
12. Manometer
13. Air box damper
14. Orifice meter
15. Manometer
16. Air Tank
17. Diesel tank
18. Burette
19. Thermocouple
20. Gas analyser
21. Smoke meter
22. Sensor
23. JO tank
24. Heat exchanger tank.

Fig. 1. Schematic layout of the test engine setup.

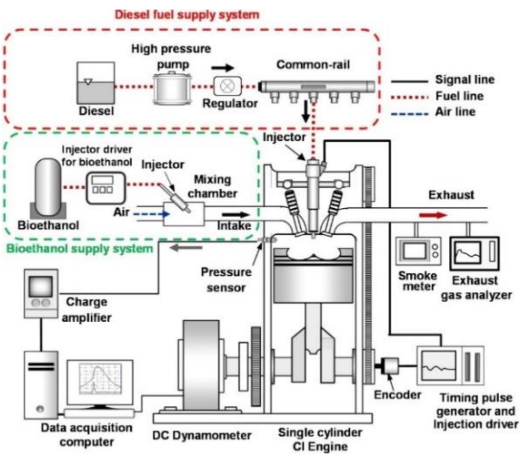


Fig. 2. Schematic layout of biodiesel engine setup.

The key to establishing stability was the observation of homogeneity of the mixture for a specified period of time. The entire setup of biodiesel engine is schematically shown in Fig. 2. The blends were observed for a time period of 36 hours, and it was observed that uniformity of the mixture was obtained [7, 8]

3. Algae biodiesel-preparation

The source of algae selected was Gracilaria edulis which is available in the geographical region of Narasaraopet, Andhra Pradesh (160 15’ N, 800 4’E). The algae samples were collected from the local ponds and shade dried; the obtained dried biomass was made into powder with the use of mortar and pestle. The powder was mixed with solvents like n-hexane. The purpose of using n-hexane is that the property of biodiesel is determined by the neutral lipids present in microalgae [9, 10]. The n-hexane solvent only extracts the neutral lipids from the cells of the algae. The entire process was done using the Soxhelt apparatus. After running the apparatus, the quantity of oil obtained is less in quantity; hence, the number of cycles was increased to obtain oil in considerable quantities. The oil obtained was taken for the process of transesterification.

A mixture of methanol, sulfuric acid, and solvent (n-hexane) was added to the algal oil, and the reaction mixture was blended for 35 minutes at a temperature of 75^{0}C. After the reaction was completed, the samples were cooled down to room temperature, and the crude ester layer (the upper phase) was separated from the glycerol layer in a separating funnel. The raw ester layer contained methyl ester, possibly unreactive oil, methanol, and glycerol [15-22]. To separate the methanol, the organic layer was washed 2 times with distilled water in a separating funnel. The fuel properties of UCME (with the additive of 2% algae biodiesel by volume) and diesel are shown in Table 1.

Table 1. Fuel properties.

Property	*Diesel*	*UCME*
Density (kg/m^3)	840	789
Kinematic viscosity (cSt)	2.44	1.52
Heating value (kJ/kg)	42,500	29,800
Cloud point (^{0}C)	3	25
Pour point (^{0}C)	6	113
Flash point (^{0}C)	70	17

4. Experimental procedure

- The engine was operated at a constant speed, 1500 rpm, and the fuel injection timing was kept at 26 before the top dead center, and other engine parameters as specified above.
- The blends of diesel, biodiesel U10D, U20D, and U30D were prepared and observed for the sustainability of mixtures.
- Fuel injection pressures of 180, 220, and 260 bar (the optimum pressure to get better performance of diesel engine and to attain

complete combustion) were used for naturally aspirated condition and supercharged condition of engine testing [22-30].

- The calorific values of different blends were measured in the laboratory; the values for U10D, U20D, and U30D are 40725, 39000, and 37510 kJ/kg, respectively.
- The engine was first run under naturally aspirated conditions and then under supercharged conditions. The supercharged conditions of the diesel, U10D, U20D, and U30D are denoted as DS, U10Ds, U20Ds, and U30Ds for easy reference.
- A cooling water outlet temperature of 55^{0}C was maintained throughout the engine operation.
- Fuel consumption, exhaust emissions concentration, and smoke were measured after the engine attained the steady-state condition.

5. Results and discussion

The tests were conducted at different injection pressures as mentioned, at constant engine speed and different loads. The experimental results showed that the fuels exhibit different combustion and performance characteristics for different engine loads and injection pressures. Examination of the fuel injection characteristics of the mixed fuels favors the usage of UCME as a fuel in a diesel engine. The maximum cylinder pressure, rate of pressure rise, and heat release rate are slightly lower for UCME blends due to its lower heating value. The brake specific fuel consumption and brake specific energy consumption for UCME blends are higher than those for diesel fuel, while the brake thermal efficiency of UCME blends is usually lower than that of diesel fuel [31-36].

Brake specific fuel consumption graphs are shown in Fig. 3 at a full load of engine operation. It is observable that as the injection pressure increases, the BSFC value increases in all cases. U10D, U20D, and U30D shows values lower in comparison to diesel. Supercharging of the engine increases fuel economy, which can be observed as lower fuel consumption for U10DS and U20DS.

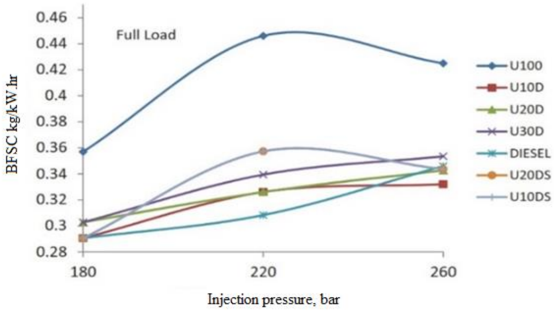


Fig. 3. BSFC vs injection pressure at full load of engine.

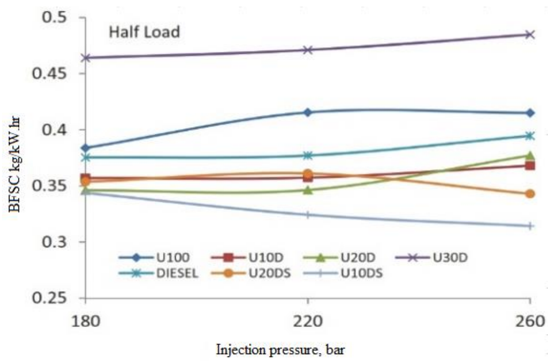


Fig. 4. BSFC vs injection pressure at half load of engine.

Fig. 4 shows the graph of BSFC versus injection pressure at a half load of the engine. It is evident that there is a rise in BSFC with injection pressure. U10D, U20D, and U30D showe high BSFC values compared with diesel. U10DS shows a value a little low compared with U10D. Brake thermal efficiency values seem to decrease with an increase in fuel injection pressure. Supercharging supports the combustion with improved air density, thus giving good thermal efficiency compared with natural aspiration.

From Fig. 5 it can be observed that with a fuel injection pressure of 220 bar, the thermal efficiency is high for the maximum duration of the engine operation. Fuel U10D at a half load shows an observable rise in thermal efficiency at 220 and 180 bar. It can be mentioned that with fuel U100, the suitable injection pressure is 220 bar. It is observable that the thermal efficiency is comparable for pure diesel and biodiesel blends of 20%. Blending more than 20% of biofuel in diesel causes a rise in BSFC and a lower energy release, leading to lower thermal efficiency.

6. Nitrous oxide emissions

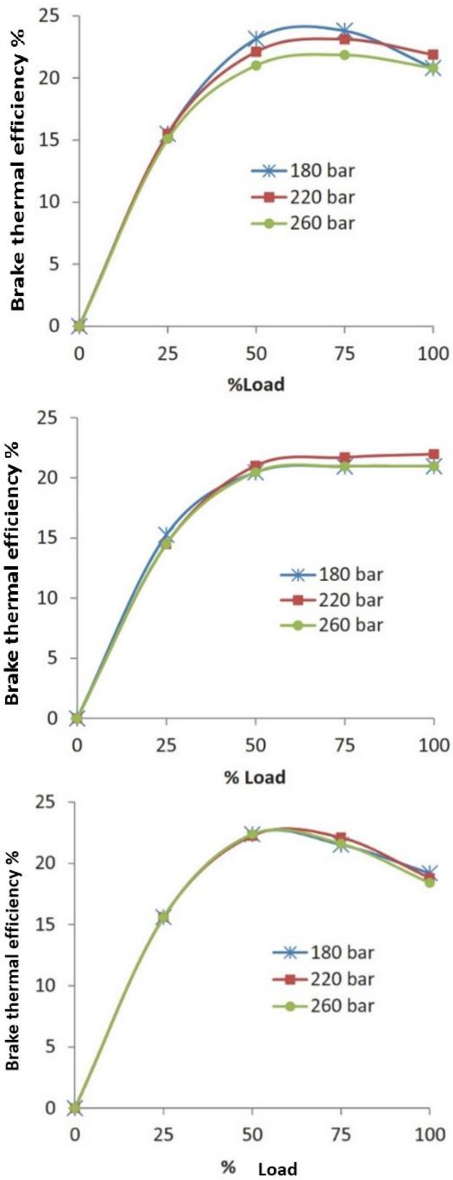
Nitrous oxide formation is merely a temperature-based phenomenon; NOx emissions increase with the increase of temperature [34-42]. With an augment in injection pressures, good atomization of the fuel with air occurred, which leads to a rise in the maximum temperature of combustion. From Fig. 6, it can be seen that with a rise in injection pressure, there is a rise NOx emission. However, in the case of biodiesel blends, the NOx emissions are slightly high; the reason for this may be the presence of nitrogen in the biodiesel.

7. Unburnt hydrocarbon emissions

A slight rise in unburnt hydrocarbons in the exhaust was observed with a rise in injection pressure.
As the UCME content in the diesel increased, there was a rise in hydrocarbons in the exhaust due to inefficient combustion. The graph of unburnt hydrocarbons against the engine load is shown in Fig. 7. U100 shows higher values of UBHC at all selected injection pressures.

8. Smoke emissions

A slight rise in smoke emissions was observed with a rise in injection pressure. But the variation of smoke emissions was low with the variation of injection pressure. An observable reduction in smoke emissions was noticed when the engine was run with biodiesel–diesel blends.



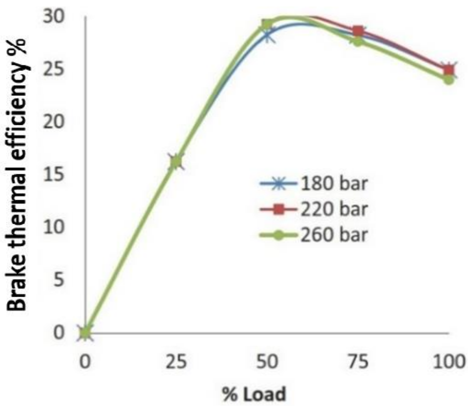


Fig. 5. Brake thermal efficiency vs engine load at different injection pressures.

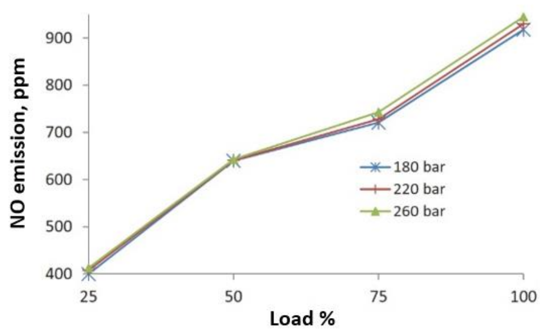


Fig. 6. NOx emissions vs Injection pressure.

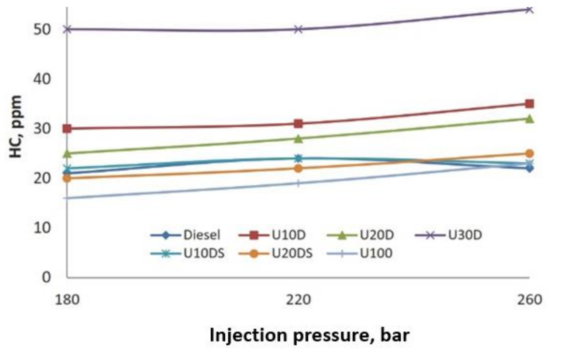


Fig. 7. Unburnt hydrocarbon emissions vs injection pressure.

9. Conclusions

- An experimental investigation on a constant-speed diesel engine fueled with used cooking oil biodiesel with the addition of esters of algae yielded the following outcomes: BSFC of all the selected fuels had low values at low injection pressures at the full load and half load of engine operation.
- BTE values of the engine for all selected fuel options were better at an injection pressure of 180 bar for the maximum duration of the engine operation.
- Supercharging had a significant effect on engine operation, with a positive outcome of a reduction in BSFC and rise in BTE values compared with the same fuel with the naturally aspirated condition.
- With supercharging the problem of increased ignition delay with biofuels can be best treated.
- For the engine to run with supercharging, low to moderate fuel injection pressure (220 bar in the present case) may be advisable.
- With the increase in injection pressure a slight rise in NOx emissions was observed at all loads of engine operation, and the unburnt hydrocarbon emissions were less at low injection pressures.
- The injection pressure of 220 bar can be suggested for this test engine considering the BSFC, BTE, and emissions of UBHC and NOx.

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