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Combustion Analysis using Third Generation Biofuels in Diesel Engine

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In this study the use of *Chlorella vulgaris* biodiesel blends are tested in a naturally aspirated dual fuel diesel engine with various load conditions at a rated speed of 1500 rpm. In the engine, the test fuels such as B20 injection, B20 blending and diesel were prepared and tested. The combustion characteristic has provided a better understanding of the operation of the engine in dual-fuel mode. The combustion analysis was done at the injection timings of 23° angle before top dead centre with an injection pressure of 220 bars. The results show that 20% blend of *Chlorella vulgaris* microalgae biodiesel with 80% diesel produced higher cylinder pressures, heat release rate, lower combustion duration, and ignition delay as compared to diesel fuel. The experimental outcomes indicate that the usage of algae oil blend in diesel engine is a feasible option.

Keywords: *Chlorella vulgaris* algae oil, Biodiesel, Blending, Injection, Combustion

Introduction

In the automotive field of study, diesel engines are commonly used around the world due to their higher combustion efficiency, reliability, flexibility as well as cost-effectiveness. However, diesel engines are among the main contributors to environmental pollution. The primary harmful pollutants from these engines are NOx and particulates. The latter is made up of various types of chemical compounds, such as elemental carbon, organic carbon, inorganic ions, etc. These particles have incredibly harmful effects on human health and deteriorate the environment. Numerous studies have shown that these particles are responsible for respiratory and cardiovascular problems as well as neurodegenerative disorders.[1] To reduce such emissions researchers have considered improvement in the diesel engine, and one of the approach presented is chasing the conventional diesel engine to a dual-fuel engine.[2] This conversion aims to reduce polluting emissions and fuel costs by using renewable fuels, which are of great interest in protecting the environment as well as reducing the pressure on the exhausting fossil fuels stock. Several researchers have studied such type of engine using biodiesel as the primary fuel.[3] It should be noted that biodiesel is a recommended fuel for engines that have a high compression ratio. The importance of its octane number allows its excellent performance in the engine. For dual-fuel operation under normal conditions, the ignition of biodiesel requires the presence of pilot fuel, though in small amount.[4] Also the other requirement is that the dual-fuel engine requires an extended combustion time and a late ignition. Also, using a fuel with a high cetane number, the self-ignition time can be reduced along with reduced exhaust emissions. Various gaseous fuels (propane, methane, natural gas, hydrogen, LPG, etc.) can be used in dual-fuel mode, without compromising with engine performance while still reducing the polluting emissions.[5] The important parameters are the substitution rate, the advance at injection, the engine load, and the temperature of the intake air. Dual-fuel mode engines use two fuels that burn simultaneously in the cylinder. It uses a pilot fuel and a primary fuel that is gaseous with the majority of the energy introduced into the engine. This type of internal combustion engine works by self-ignition of the pilot fuel injected into a highly compressed primary air-fuel mixture.[6] Literature search shows that the use of biodiesel offers an impressive renewable energy option. It guarantees the supply of energy and is already helping to reduce specific polluting emissions. The dual-fuel engine mode powered by different blend, has influenced many researchers, intending to improve engine combustion while saving fuel. The study investigated the use of *Chlorella vulgaris* biodiesel (20% biodiesel-diesel blends, v/v) in compression

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ignition engine. The detailed combustion parameters such as higher cylinder pressures, heat release rate, combustion duration and ignition delay as compared to diesel fuel were investigated.

Materials and Methods

Biomass to biodiesel

The alga was cultivated, algal biomass was harvested and dried for downstream processing. Algal oil was extracted through soxhlet method[7] using hexane as solvent. The oil was transesterified[8,9] using methanol, in presence of KOH. The produced biodiesel further tested for its physical and chemical characteristics before going for various test in engine. Different steps involved in biomass to biodiesel preparation are shown in Fig. 1.

Analysis of physiochemical Properties

Algae biodiesel was taken as the fuel to blend with diesel. It was blended with diesel in successive gravimetric ratios of 20. The blend was allowed to settle for a while, and no phase separation was found. B20 (*20% Biodiesel + 80% Diesel)* was considered optimum and was used as pilot fuel and also injected in the inlet manifold. The chemical and physical characteristics of biodiesel are required for analysis, serving to verify quality. , The analysis of various characteristics of biodiesel was made using the *American Society for Testing and Material* (ASTM*).*[10] Various parameters were tested.

Experimental Setup

For the testing of the fuels, a single cylinder CI engine providing an optimum power of 5.2 kW @ 1500 RPM was operated. The running condition of the engine was kept constant with fuel to be injected at a fixed 23° angle before Top Dead Center (TDC) in the pressure level of 220 bar. The engine contains a hemispherical chamber along with overhead valves. The compression ratio on the engine was kept as 17.5. An eddy-current dynamometer was operated to load the engine. The mechanical types of pump nozzle fuel injection system, which has a three-hole injector operated an open ECU to control the quantity of alcohol to be injected. The ECU was controlled with a knob and related to the specific voltage; this particular quantity of biodiesel was injected into the engine. The ECU was connected with a centrifugal pump which in turn was connected to a similar fuel injector.[11]

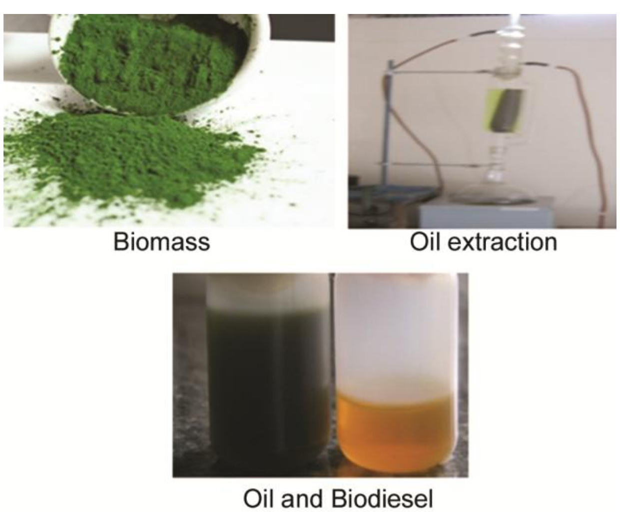

Fig. 1 — Different steps to make biodiesel

Results and Discussion

Physico-chemical properties of the test blend

The physicochemical properties of the test fuel i.e. B20 are given in Table 1. The density and kinematic viscosity (40°C) of B20 is found to be higher than Diesel. This indicates that at a given temperature, the nebulisation of B20 will be lower than that of diesel. The Flashpoint of B20 is lower than diesel which means it will catch fire faster than diesel. The calorific value and cetane index of B20 is higher than diesel. The water and sediment are present in negligible quantity. The Cloud point and Pour points indicates that except peak winters (or locations with low temperature) there should be no difficulty in using algal biodiesel.

Heat release rate

It is required to determine the heat release rate in order to compare the combustion process in both modes. The TDC can help to understand how the engine works. Heat release rate is calculated by applying the perfect gas equation while obeying the first law of thermodynamics. The change in cylinder volume and recorded values of the pressure in the cylinder are used in the following expression to obtain the TDC.

Table 1 — Physiochemical properties of the fuels

Properties	ASTM	Diesel	B20
Density (kg/m^3)	D-4052	0.840	0.860
Kinematic viscosity at 40°C (mm^2/s)	D-445	3.6	3.8
Flashpoint (°C)	D-92	7.4	4.8
Cloud point (°C)	D-2500	-4	-4
Pour point (°C)	D-97	<-5	-2
Calorific value (kJ/kg)	D-240	42700	44742
Cetane index	D-613	48	52
Water and sediment (% vol.)	D-2709	0.05	0.05

$$\frac{dQnet}{d\theta} = P\frac{\gamma}{\gamma - 1}\left(\frac{dV}{d\theta}\right) + \frac{1}{\gamma - 1}\mathrm{V}\left(\frac{dP}{d\theta}\right) \quad \ldots (1)$$

where $\frac{dQnet}{d\theta}$ is the rate of net heat generation, γ is the specific heat ratio, P is the cylinder pressure, and V represents the volume of the combustion chamber. The volume calculation involves crankshaft angle (θ), and engine's geometric parameters. The following equation gives cylinder volume V as:

$$\mathrm{V}(\theta) = V_{cyl}\,\frac{\tau_c}{\tau_c - 1} - \frac{1 - cos\theta}{2} + \frac{1}{2}\sqrt{\left[\left(2\frac{L}{C}\right)^2 - sin^2\theta\right]} \quad \ldots (2)$$

where V_{cyl}, τ_c, L and C represent the displacement, the compression ratio, the length of the rod, and the stroke, respectively.

The Heat Release Rate (HRR) variation for all test fuels with different loads is shown in Fig 2. It is noticed that the HRR increases with an increase in load, for all the fuel blends. At higher load, HRR increases for B20 Injection (B20I) compare to B20 Blending (B20B) and diesel. This is due to premixed combustion and an increase in the delay period. At the low, medium, and high load conditions, B20I, B20B, and diesel respectively showed the maximum HRR value. Due to prolonged ID, more amount of the fuel get injected which when blends with the air before the commencement of ignition leads to higher temperature. Also the higher O_2 content of the diesel promotes the combustion positively.[12]

Cylinder Pressure

Pressure data processing in the form of smoothing is essential, following the noisy trend of the pressure signal between successive values. For our case, a smoothing was established using the equation for smoothing the following instantaneous pressure data:

$$P_n = [(P_{n-1} + 2(P_n) + P_{n+1}]/4 \quad \ldots (3)$$

The cylinder pressure vs. crank angle under different load conditions is shown in Fig. 3 for all the test fuels. The peak Cylinder Pressure (CP) has increased with an increase in the load for all the fuel blends. The maximum CP is obtained for diesel, B20B, and B20I blend, respectively. At all engine loads, a retarded ignition is noticed with the diesel, which leads to an increase in the ID. The peak CP has decreased at low engine load, whereas there is no significant change in the peak CP at high engine load for diesel and B20B blends, but the drastic increase in peak CP is observed for B20I bend. The peak pressure depends upon the combustion rate during the initial stages, which will be affected by the quantity of fuel involved in the uncontrolled burning phase, which controlled by the delay period.[13]

Ignition delay

The ignition delay, defined as the crankshaft angle interval between two points. The first point represents the start of the injection, the second being the start of combustion. This interval can be determined by two methods, either from the curve of the pressure derivative, or from the curve of the rate of heat release. Diesel combustion consists of two modes, kinetically controlled premixed combustion and mixing controlled diffusion combustion. From the rate of heat release (Fig. 3), it is clear that, premixed combustion of diesel fuel starts before TDC and ends after TDC. But for B20I, due to its higher cetane number and less available mixture for combustion, premixed combustion starts earlier, and it ends shortly when compared to diesel and B20B blends. From Fig. 3, it was observed that all the B20I fuel blends, which are used as fuel, exhibit a trend of decrease in ignition delay with a load than other fuel. The difference in crank angle position between 5% mass

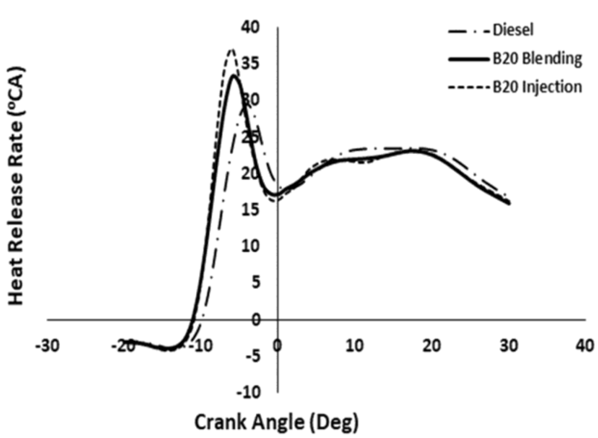

Fig. 2 — Variation of heat release rate versus crank angle

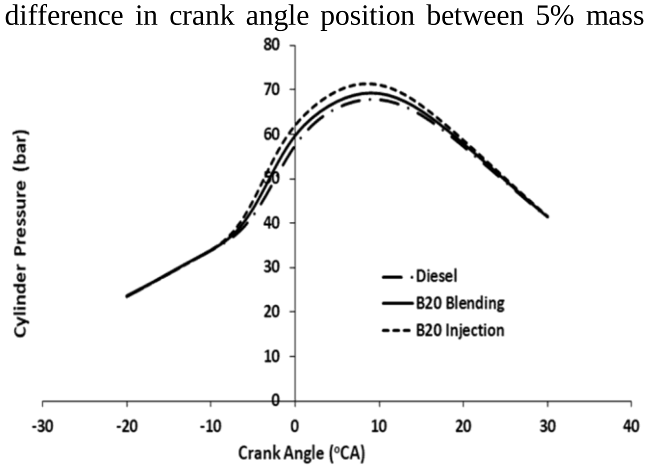

Fig. 3 — Variation of in-cylinder pressure versus crank angle

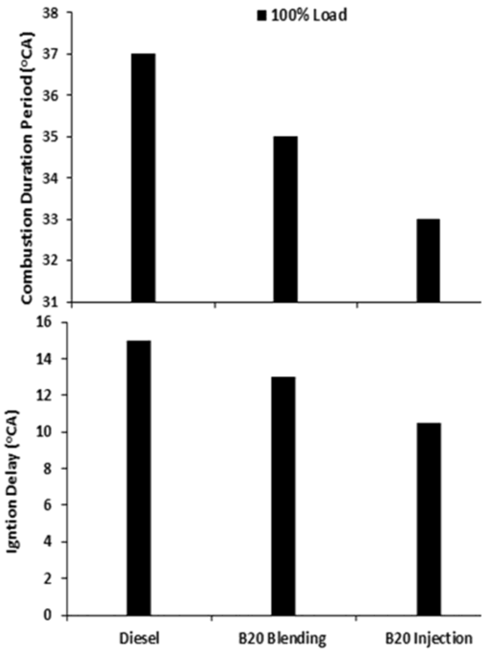

Fig. 4 — Combustion duration and Ignition delay with loads

fraction burned and 90% mass burned has been taken as combustion duration for the tested fuel blends.[14]

Combustion duration

The Combustion time is presented in terms of the crankshaft angle. It is defined between two positions, when the heat release rate takes a positive value, and the moment when 90% of the net heat is released. It was observed from Fig. 4 the combustion duration increased for diesel, B20B, and B20I blends when the engine was operating at full load. The highest values of combustion duration were observed for B20I, B20B, and diesel, respectively. The lower viscosity of B20I produced smaller size droplets, which consumed less time for preparation of the mixture for combustion than diesel and B20B.[15] At high load, the dual-fuel mode injection has a shorter combustion time than that of diesel. These findings can be explained by a short burning time of biodiesel due to the improvement in the quality of combustion. This induces a significant reduction in slow combustion.

Conclusions

The experimental study as completed in the unmodified diesel engine using algae biodiesel and diesel blends, got very promising results. Combustion results from the engine showed that, the peak pressure is recorded for the B20I followed by B20B and diesel. At the full-load issue the net heat capacity could be around 10% higher than diesel. The lower combustion duration and ignition delay are recorded for B20I, followed by B20B and diesel.

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