Performance, Combustion and Emission characteristics of a Diesel Engine with Biodiesel from Cotton Seed oil as Alternate Fuels

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Abstract:

There is an increasing interest in India to search for suitable alternative fuels that are environmental friendly. Environmental concerns and limited amount of petroleum resources have caused interests in the development of alternative fuels for internal combustion engines. Biodiesel is an alternative diesel fuel that can be produced from renewable feedstock such as edible and non-edible vegetable oils wasted frying oils and animal fats. The use of biodiesel is rapidly expanding around the world, making it imperative to fully understand the impacts of biodiesel on the diesel engine combustion process and pollutant formation. Biodiesel is known as the mono-alkyl-esters of long chain fatty acids derived from renewable feedstock for use in compression ignition engines. The objective of this research was to determine the relationship between engine performance and emissions of cottonseed oil biodiesel used in a 5.2 kW diesel engine. A methyl ester of cottonseed oil was prepared and blended with diesel in five different compositions varying from 10% to 50% in steps of 10%. The tests were conducted in a single cylinder DI diesel engine at a constant speed of 1500 rpm. Highest brake thermal efficiency and lower specific fuel consumption were observed for 20% biodiesel blend. Substantial reduction in carbon monoxide and hydrocarbon emission was observed, whereas nitric oxide emission increases at higher loads compared to petroleum diesel. Improved heat release characteristics were observed for the prepared biodiesels. The results reveal that the biodiesels can be used safely without any modification to the engine.

Keywords: *Biodiesel, Cotton seed oil, Combustion, CI engine, Performance and exhaust emission.*

1. Introduction:

India is the second largest producer of cotton seed in the world next to China with the potential of 4.6 million tones of oil seeds per annum. With the rapid development of rural agricultural production and rapid growth of local industry in India, the discrepancy between demand and supply of energy has become an increasingly acute problem. The limited resources of fossil fuels, increasing prices of crude oil, and environmental concerns have been the diverse reasons for exploring the use of vegetables oils as alternative to diesel oil [1-3]. Vegetable oils offer almost the same output with slightly lower thermal efficiency when used in diesel engines [4-6]. The use of neat vegetable oils poses some problems when subjected to prolonged usage in CI engines. These problems are attributed to high viscosity, low volatility and polyunsaturated character of vegetable oils [7-10]. Increasing global concern due to air pollution caused by internal combustion engines has generated much interest in the environmental friendly diesel fuels. These forecasts have triggered various research studies in many countries to replace petroleum based diesel fuel with oxygenated fuels such as biodiesel, ethanol etc. Although the fuel properties of biodiesel show some variations when different feed stocks are used, it has higher cetane number, near-zero aromatic, and free sulphur compared to conventional diesel fuel [11-14]. The fuel properties of biodiesel are affected by its fatty acids content which causes differences in the injection, combustion, performance and emission characteristics of the engine. Many researchers have concluded that biodiesel holds promise as an alternative fuel for diesel engines, since its properties are very close to diesel fuel. The fuel properties of biodiesel such as cetane number, heat of combustion, gravity, and viscosity influence the combustion and so the engine performance and emission characteristics because it has different physical an chemical properties than petroleum-based diesel fuel [15-16]. The combustion timing in CI engines is mainly affected by the start if injection and the ignition delay, which is the time between the start of injection and start of combustion. The ignition delay time is mostly affected by cetane number. The biodiesel has higher cetane number than diesel fuel, therefore shortens ignition delay time and advances the combustion timing [7].

The fuel properties of the synthesized biodiesel were determined and their performance, emission and combustion characteristics were studied on a four-stroke, single cylinder direct injection diesel engine to ensure their suitability as CI engine fuel.

2. Experimental System Development for Biodiesel Production:

The raw cottonseed oil was extracted by mechanical expeller in which small traces of organic matter, water and other impurities were present. Biodiesel, which is synthesized by transesterification of vegetable oils or animal fats sources, is a realistic alternative of diesel fuel because it is produced from renewable resources and involves lower emissions than petroleum diesel. The processed form of vegetable oil (biodiesel) is considered as the potential fuel to replace petroleum diesel in CI engines. The transesterification process combines the oil with an alcohol. The most common form of biodiesel is made with methanol and vegetable oils in the presence of a suitable catalyst. Additionally, the process yields glycerol.

3. Methodology:

Transesterification is a most common and well established chemical reaction in which alcohol reacts with triglycerides of fatty acids (vegetable oil) in presence of catalyst to form glycerol and esters. The ester preparation involved a two step transesterification reaction followed by washing and drying. The two step reaction utilized a 100% excess methanol, or a total molar ratio of methanol-to-oil of 6:1 with methanol equally divided in two steps. 1000gm was placed dry flask equipped with a magnetic stirrer and thermometer. In another flask, approximately 300gm of methanol was mixed with 7gm of NaOH until all of the catalyst dissolved. This mixture was quickly added to the oil and stirred vigorously for 1 hr maintaining temperature 60-65degree Celsius [11]. After 24 hr, ester layer is set up on upper part and glycerol is set up on lower part. Then using separating funnel separates glycerol and ester is poured into another flask. Finally the ester was dried by silica gel.

4. Characterization of biodiesel:

The source of cottonseed oil is cottonseed, which is a crop by product. It is basically a triglyceride ester with a number of branched chains of 8-18 carbon atoms. It contains 85.3% fatty acids. Fatty acid composition of the oil is essential to determine the quantity of reactants and the catalyst. Free fatty acids can be determined from the acid value. It has been stated that the acid value 6:1 gives the maximum conversion efficiency. The significant properties of cotton seed oil are found during the present investigation.

Table 1: Properties of pure biodiesel

S. N.	Properties	ASTM standard	CSME 100	DIESEL
1	Density in gm/cc	ASTM D 4052	0.874	0.825
2	Viscosity in centistoke	ASTM D 445	4.2	2.25
3	Flash point ^{0}C	ASTM D 93	142	66
4	Pour Point ^{0}C	ASTM D 2500	0	10
6	Calorific Value (MJ/Kg.)	ASTM D 6751	40.6	42.00
7	Cetane number	ASTM D 6751-02	51.2	48
8	Sulphur content (mg/Kg)	ASTM D 5453	51	496

5. Experimental setup:

The experiment was set up using the following equipment. The engine used for experimentation is a Kirloskar make Single cylinder, four-stroke, and water cooled TV1 computerised diesel engine used in agricultural application. The bore and stroke of engine is 87.5 mm and 110 mm respectively. The compression ratio is 17.5, which gives 5.2 kW rated output at 1500 rpm loaded mechanically. The piezo sensor is having a range of 5000 PSI. The crank angle sensor is having a resolution 1 Deg, speed 5000 rpm with TDC marker pulse. Engine indicator is used for data scanning and interfacing, with speed indicator. Rotameter is used for water flow measurement. Digital thermocouple type temperature sensors are used as temperature indicator. A non-dispersive infrared analyser (NDIR), AVL DIGAS was used for the measurement of carbon monoxide (CO), nitric oxide (NO), unburnt hydrocarbon (HC).

All the experiments were conducted at a rated speed of 1500 rpm. No adjustment was made at the fuel injection timing that is at 23^0 BTDC (static) was used for diesel and biodiesel respectively. The cooling temperature was maintained at 70^{0}C during all the experiments. The experiments were conducted by using diesel, B10, B20, B30, B40 and B50 (50% CSME +50% DIESEL), at different load conditions on the engine from 0% to 100% in appropriate steps of 25%. In each experiment, engine parameters related to thermal performance of the engine are measured.

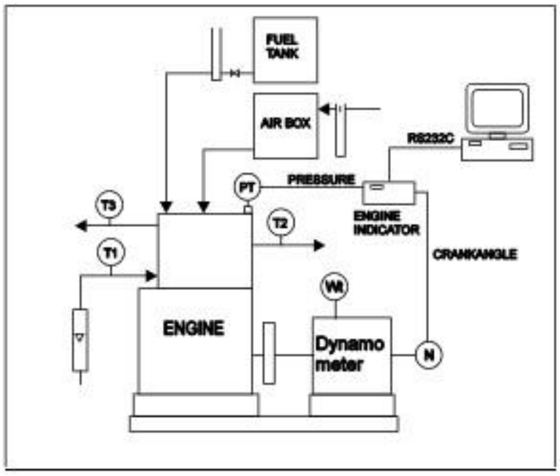

Figure 1: Schematic of Experimental Setup

6. Experimental procedure:

Tests have been conducted on a four stroke, direct injection; naturally aspirated single cylinder diesel engine is employed for the present study. The detail specification of engine is given in above table 1. The injection was performed at a static injection timing (optimum) of 23^o BTDC set for diesel fuel. To obtain the baseline parameters, the engine was first operated on diesel fuel. Performance and emission tests are carried out on the diesel engine using CSME, and its various blends. The tests are conducted at the rated speed of 1500 rpm at various loads and blends are prepared by volume basis i.e. CSME10, CSME20, CSME30, CSME40, CSME50. Similar experiments were conducted over the same diesel engine. The experimental data generated are documented and presented here using appropriate graph.

In each experimental phase, engine parameter is related to thermal performance of the engine such as brake thermal efficiency; specific fuel consumption and applied load are measured. Mainly, at the given loading conditions, comparative analysis of the engine performance on the CSME, and its blends with diesel and their emission were investigated. Load on the engine is steadily increased. At each interval the readings are taken on the manual instrumentation or logged onto the computer analysis software; the variables gathered can then be used with the engine specifications to calculate characteristics which determine the performance of the fuel on the engine during operation.

7. RESULTS AND DISCUSSIONS:

Engine Performance Parameters:

The performance of DI-CI engine was evaluated in terms of fuel consumption, brake specific fuel consumption and brake thermal efficiency, which were discussed as follows:

7.1. Brake thermal efficiency:

The variation of brake thermal efficiency with respect to load for both fuels and its blends is as shown in the following graph. Brake thermal efficiency of CSME and its blends increases with the increase in load and, after reaching maximum value, efficiency decreases with the increase of load. The BTE increases as the output power increases for both fuels.

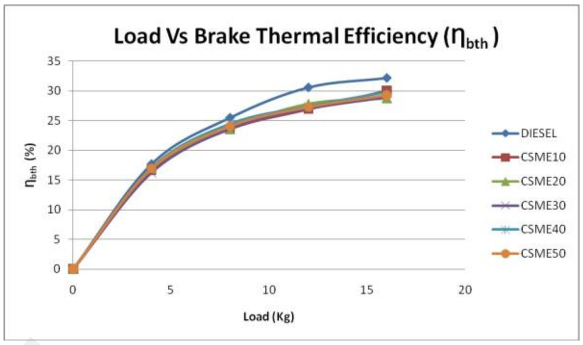

Figure 2: Variation of brake thermal efficiency for CSME Blends and diesel

7.2. Brake Specific Fuel Consumption:

In case of biodiesel mixtures, the BSFC values were determined to be higher than those of neat diesel fuel, and thus more biodiesel mixtures were required for the maintenance of a constant power output. BSFC is inversely proportional with the BTE. The slight reduction of BTE with biodiesel mixtures was attributed to poor spray characteristics, poor air fuel mixing.

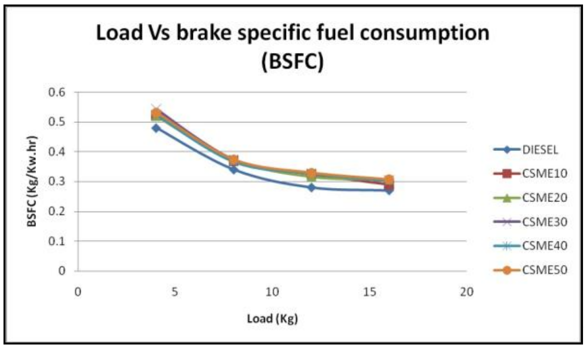

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Figure 3: Variation of brake specific fuel consumption for CSME blends and diesel

7.3. Indicated Power

The variation of indicated power with respect to load for both fuels and its blends is as shown in the following graph: The indicated power is slightly lower for CSME blends than diesel.

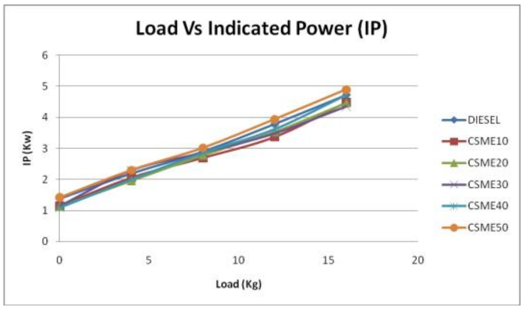

Figure 4: Variation of indicated power for CSME Blends and diesel

The biodiesel also contains some amount of oxygen molecule in the ester form. It is also taking part in the combustion .For CSME20, This reveals that the effective combustion is taking place and there is saving with respect to exhaust gas energy loss. This fact is reflected in brake thermal efficiency and brake specific fuel consumption as well.

7.4. Mechanical efficiency

The variation of mechanical efficiency with respect to load for both fuels and its blends is as shown in the following graph. The mechanical efficiency for JME blends and diesel are close to each other.

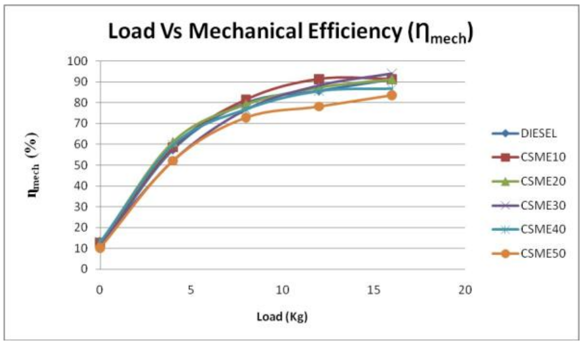

Figure 5: Variation of Mechanical efficiency for CSME Blends and diesel

8. Engine Emission parameters:

Following Engine Emission parameters are evaluated for CSME and its blends with diesel.

8.1. Carbon monoxide

The variation of carbon monoxide with respect to load for both fuels and its blends is as shown in the following graph. The formation of CO emission mainly depends upon the physical and chemical properties of the fuel used. It is observed that, the CO emission of cottonseed biodiesel is less than that of diesel fuel. CO is predominantly formed due to the lack of oxygen. Since CSME is an oxygenated fuel, it leads to better combustion of fuel resulting in the decrease in CO emission.

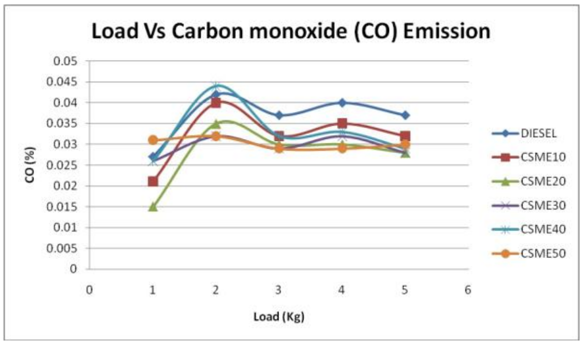

Figure 6: Variation of carbon monoxide for CSME Blends and diesel

8.2. Hydrocarbons:

The variation of hydrocarbons with respect to load for both fuels and its blends is as shown in the following graph. HC emissions reduced drastically, but the higher HC emissions are observed for the blend at low load conditions. At low load conditions the quantity of fuel injected is lower resulting in a leaner mixture, quenching of flame and lower gas temperature results in incomplete combustion leading to higher HC emissions.

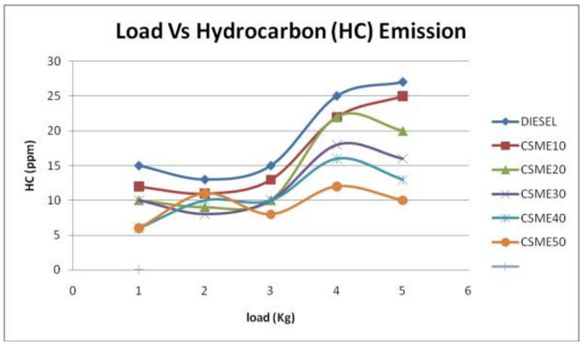

Figure 7: Variation of Hydrocarbons for CSME blends and diesel

8.3. Carbon dioxide:

Fig. 8 shows that, for both fuels, the increasing trend of carbon dioxide (CO2) emission levels are observed with power output. This increasing trend of CO2 emission is due to increase in volumetric fuel consumption. It is observed that, the CO2 emission of cottonseed biodiesel is less than that of diesel fuel. This is attributed to the presence of oxygen and high cetane number of cottonseed biodiesel.

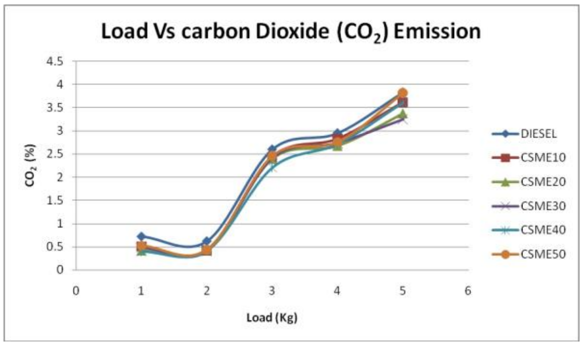

Figure 8: Variation of Carbon dioxide for CSME blends and diesel with load

8.4. Nitrogen oxide:

The variation of nitrogen oxide with respect to load for both fuels and its blends is as shown in the following graph and bar chart. Results show that, for both the fuels, the increased engine load promoting NOx emission. The cottonseed biodiesel is producing slightly more NOx than diesel. The increase in NOx emission is attributed to the presence of mono-unsaturated and poly-unsaturated fatty acids present in the cottonseed biodiesel. NOx gradually increases with the increase in percentage of CSME in the fuel. The NOx increase for CSME may be associated with the oxygen content of CSME.

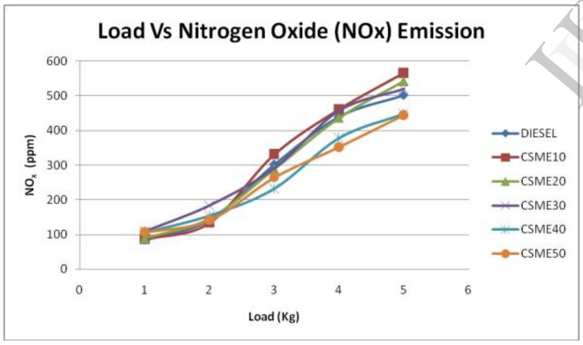

Figure 9: Variation of nitrogen oxide for CSME blends and diesel

9. Conclusions:

The performance, emission and combustion characteristics of a single cylinder direct injection CI engine fuelled with CSME and its blends have been analyzed and compared to the base line diesel fuel. The results of present work are summarized as follows.

- The specific fuel consumption increases with increase in percentage of CSME in the blends due to the lower calorific value of CSME.
- Peak power produced when using CSME blends failed to match the peak power produced when using neat diesel.
- The brake specific fuel consumption tended to increase when using biodiesel blends, especially in blends with a high percentage of biodiesel, such as B40 and B50.
- The tests on engine running with different fuels (biodiesel and diesel) have resulted in almost overlapped P-V diagrams. The engine running with biodiesel has produced slightly higher in-cylinder pressure and peak heat release rate than the engine running with normal diesel.
- CO emissions tended to decrease as the percentage of CSO biodiesel increased. Total hydrocarbon emissions decreased as the percentage of CSO biodiesel increased. NOx emissions were equal when using B20.
- A general practical conclusion is that, all tested biodiesel blends can be used safely without any modification in engine. So, blends of methyl ester of cottonseed could be successfully used.

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