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EXPERIMENTAL INVESTIGATION OF NON EDIBLE COTTON SEED OIL BIODIESEL IN SINGLE CYLINDER DIESEL ENGINE

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Abstract— Biodiesel is a clean renewable fuel which has many environmental advantages. Due to unavailability of fossils fuels reserves and environmental problems, the use of biofuels in compression ignition engines are now a consideration attention in place of petrochemicals. However, due to the higher density and viscosity of biodiesel, pure biodiesel is not widely used in diesel engines. Therefore, the purpose of fuel additive is to improve the viscosity and density in the biodiesel blend. Biodiesel was produced from high Free Fatty acid cotton seed oil using transesterification process. Cotton seed oil was characterized for its physical, chemical and thermal properties. Performance and emission characteristics of biodiesel and its blends were compared with the baseline data of diesel in a compression ignition engine.

Keywords— Cotton Seed Oil, BTE, BSEC, CO, CO_2, UHBC and NO_X

INTRODUCTION

Biodiesel has become an alternative fuel because of its biodegradability and non-toxicity. Biodiesel production can be traditionally divided into three main groups i.e. vegetables oils, animal fats and waste cooking oils (used oily materials). Vegetables oils can be further categorized into 2 main parts i.e. edible oils and non-edible oils. There are different kinds of vegetable oils which depend upon climatic and soil conditions, which are conventional feedstock for biodiesel production such as rapeseed oil in Canada, sunflower oil in Europe, soya bean oil in U.S., palm oil in Southeast Asia, coconut oil in Philippines, etc. Due to rapid growing population, the consumption of edible oils can cause significant problems for instance, starvation in developing countries. The non-edible oils have been used because of its low cost. The non- edible oils from Jatropha, Karanja, neem, Cotton Seed and other plants are used for biodiesel production. [1]

‘‘Biodiesel’’ is defined as a mono alkyl ester of fatty acids or fatty acid methyl or ethyl ester derived from renewable feed-stocks, such as vegetable oils. The term ‘‘bio’’ indicates the biological source of biodiesel, in contrast with conventional diesel [2]. Biodiesel is a clear liquid with a light-to dark-yellow color. It has a boiling point of over 200° C, a flash point between 145–175°C , a distillation range of 195–325°C, and a vapour pressure (mm Hg at 22°C) less than 5. It is also insoluble in water, having a light musty/soapy smell, biodegradable, and has stable reactivity [3].

There are number of methods through which the viscosity of fuel decreases so that the fuel will have the same property to be used as an engine fuel. The following procedures to be adopted to produce a better quality of biodiesel are blending of crude oils, micro-emulsions, pyrolysis and trans-esterification [4, 5].

Blending of crude oils or dilution

Crude vegetable oils can be mixed directly or diluted with diesel fuel to improve the viscosity so as to solve the problems associated with high viscosities in compression ignition engines. Caterpillar Brazil, in 1980, used a 10% mixture of vegetable oil to maintain total power without any alteration or adjustment to engines. A blend of 20% vegetable oil and 80% diesel fuel was also successfully reported [6]. Dilution with 25 parts of sunflower oils with 75 parts of diesel with a viscosity of 4.88 cSt at 40 ◦C have been studied [7].

Micro-emulsification

Another method to reduce the viscosity of vegetable oils is by micro-emulsion. Micro-emulsions are clear, stable isotropic fluids with three components: an oil phase, an aqueous phase and a surfactant. The aqueous phase may contain salts or other ingredients, and the oil may consist of a complex mixture of different hydrocarbons and olefins. This ternary phase can improve spray characteristics by explosive vaporization of the low boiling constituents in the micelles. All micro-emulsions with butanol, hexanol and octanol can meet the maximum viscosity limitation for diesel engines [8].

Pyrolysis

Pyrolysis is the process of conversion of one substance into another by means heat or with the aid of catalyst in the absence of air or oxygen. The material used for pyrolysis can be vegetable oils, animal fats, natural fatty acids and methyl ester of fatty acids. The viscosity of the pyrolyzed soybean oil distillate is 10.2 cSt at 37.8 ◦C, which is higher than the ASTM specified range for diesel fuel but acceptable as still well below the viscosity of soybean oil [9].

Trans-esterification

Trans-esterification is the chemical reaction that involves triglycerides and alcohol in the presence of a catalyst to form esters and glycerol. This trans-esterification involving three consecutive reversible reactions, they are the conversion of triglycerides to diglycerides, followed by the conversion of diglycerides to monoglycerides. Glycerides are then converted into glycerol, giving one ester in each step. A catalyst is usually used to improve and enhance the reaction rate so that the reaction can be completed in a shorter reaction time. Several catalysts have been investigated for the purpose of trans-esterification by many researchers. Examples are magnesium, calcium oxides and carbonates of basic and acidic macro-reticular organic resins, alkane alumina, phase transfer catalysts, sulphuric acids, p-toluene sulphonic acid and dehydrating agents as a co-catalyst [10]. However, basic catalysts are usually favored over acid catalysts because of the higher reactivity and the milder process conditions such as the lower temperature required [11]. Due to this trans-esterification being reversible, excess alcohol is used to shift the equilibrium towards the product. A successful trans-esterification reaction produces ester and crude glycerol. Though esters are the desired products of trans-esterification reactions, glycerin recovery is also important due to its numerous applications in daily products [12]. The trans-esterification reaction can be catalysed by alkalis, acids or enzymes [13, 14].

The overall trans-esterification reaction is given by three consecutive and reversible equations as shown below.

Triglyceride (TG) + ROH ↔ Diglyceride (DG) + $RCOOR_1$ (1)

Diglyceride (DG) + ROH ↔ Monoglyceride (MG) + $RCOOR_2$ (2)

Monoglyceride (MG) + ROH ↔ Glycerol + RCOOR (3)

EXPERIMENT AND PROCEDURE

Cotton seed methyl ester was prepared in laboratory by trans-esterification process. The required quantity of oil and methanol molar ratio of 1:6 was used with KOH (1%) as catalyst. Oil was heated to 55°C to 60°C and the mixture of methanol with KOH in the desired proportion was added. The mixture was agitated for an hour and then left for settling for 24 hours. After removal of glycerol from the mixture, the ester was washed with water thrice and excess methanol was finally separated.

The present study considered 0%-20%, blend of methyl ester in diesel with its effect of engine performance. The test fuel samples were prepared by volume wise substitution of diesel in the blend. This study was carried out to investigate the performance and emission characteristics of cotton seed oil methyl ester in a single cylinder four-stroke diesel engine and compare it with baseline data of diesel fuel. Kinematic viscosity was measured using kinematic viscometer. Calorific value and density were measured using bomb calorimeter and density meter respectively.

The fuel properties of diesel and blends of methyl ester were determined as per ASTM standards and are listed in Table 1.

Properties	D100	B5	B10	B15	B20	B100	Cotton Seed oil
Kinematic Viscosity (mm^2/sec)	3.10	2.90	2.98	3.10	3.25	6.02	38.80
Density (kg/m^3)	822	833	836	839	842	887	922
Calorific value (cal/gm)	10948.10	10534.97	10335.40	10105.92	10048.50	9302.04	9031.72

A Kirloskar make, single cylinder, air cooled, direct injection diesel engine was selected for the present research work. It is a single cylinder, naturally aspirated, four stroke, vertical, air-cooled engine. It has a provision of loading electrically since it is coupled with single phase alternator through flexible coupling. The cylinder is made of cast iron and fitted with a hardened high-phosphorus cast iron liner. The lubrication system used in this engine is of wet sump type, and oil is delivered to the crankshaft and the big end by means of a pump mounted on the front cover of the engine and driven from the crankshaft. The inlet and exhaust valves are operated by an overhead camshaft driven from the crankshaft through two pairs of bevel gears. The fuel pump is driven from the end of camshaft.

Specifications of the Single Cylinder Diesel Engine

No. of cylinders	1
No of strokes	4
Fuel	H.S. Diesel
Rated power	3.5 kW@1500 RPM
Cylinder Diameter	87.5mm
Stroke length	110mm
Connecting rod length	234mm
Compression ratio	18
Orifice diameter	20mm
Dynamometer arm length	185mm

For conducting the desired set of experiments and together required data from the engine, it is essential to get the various instruments mounted at the appropriate location on the experimental setup. Apart from this, a dual fuel system has been developed for diesel and cotton seed oil.

Overall pictorial view of the test rig along with instrumentation used in the present investigations is shown in Figure.

EXPERIMENTAL PROCEDURE

The engine was started at no load by pressing the exhaust valve with decompression lever and it was released suddenly when the engine was hand cranked at sufficient speed. After feed control was adjusted so that engine attains rated speed and was allowed to run (about 30 minutes) till the steady state condition was reached. With the fuel measuring unit and stop watch, the time elapsed for the consumption of 10, 20 and 30 cc of fuel was measured and average of them was taken. Fuel Consumption, RPM, exhaust temperature, smoke density, CO, NO_x , HC , CO_2 and power output were also measured. Fuel leakages from the injector were measured with small measuring cylinder. The engine was loaded gradually keeping the speed with in the permissible range and the observations of different parameters were evaluated. Short term performance tests were carried out on the engine with diesel to generate the base line data and subsequently neat cotton seed oil was used to evaluate its suitability as a fuel. The performance and emission characteristics of neat cotton seed oil were evaluated and compared with diesel fuel. When the dual mode fuel engine was to run with cotton seed oil, a heat exchanger was used and is connected with the help of a bypass line of exhaust gases. The cotton seed oil was heated to the different desired fuel inlet temperature and their performance and their performance and emission characteristics were evaluated. These data were than compared with both the diesel fuel and cotton seed oil biodiesel. The engine was always started with diesel as a fuel and after it was run for 20-25 minutes, it was switches over to cotton seed oil. Before turning the engine off, the cotton seed oil was replaced with diesel oil and it was run on diesel oil till all cotton seed oil in fuel filter and pipe line is consumed.

PERFORMANCE CHARACTERISTICS

The performance characteristics of the test engine on Diesel and cotton seed oil were summarized below:

BRAKE THERMAL EFFICIENCY

The variation in brake thermal efficiency (BTE) of the engine with cotton seed blends at different pressure is shown in Figure. It is compared with baseline data of diesel and unheated cotton seed oil. It has been observed that initially with increasing load; the Brake Thermal Efficiencies of all the blends of cotton seed oil were increased and then tends to decrease with further increasing in Brake power. The brake thermal efficiency of cotton seed oil was lower than diesel fuel. The main reason for partial reduction in thermal efficiency of cotton seed oil is lower calorific value and high viscosity as compared to diesel fuel. At full load condition, the BTE is lower for B5, B10, B15 and B20 as compared to diesel. This is due to the fact that biodiesel have higher viscosity and lower heating value than diesel fuels. Reduction in lower calorific value and high viscosity cause improper atomization of the blends as compared to diesel fuel. The thermal efficiency of B5, B10, B15 and B20 were 25.82%, 25.015, 24.01% and 22.40% respectively whereas the thermal efficiency of diesel was 26.71%.

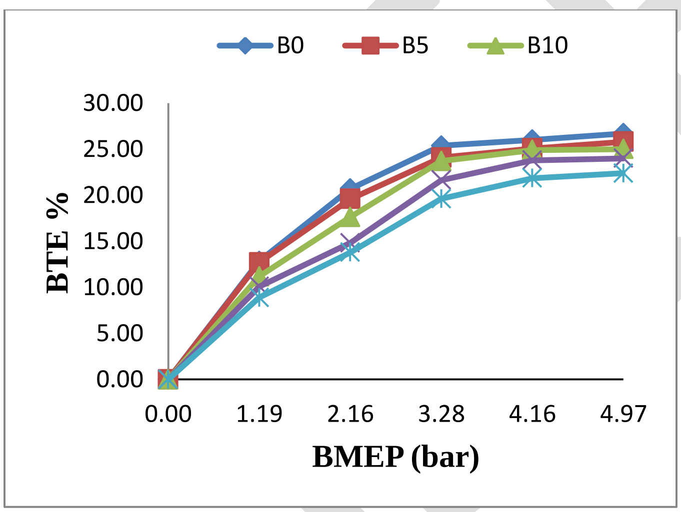

Fig BTE versus BMEP

BRAKE SPECIFIC ENERGY CONSUMPTION

Brake specific energy consumption (BSEC) is defined as how the amount of input energy required to develop one-kilo watt power. Figure shows the variation of BSEC for neat diesel and cotton seed oil biodiesel blends. It was observed that the BSEC is lower for B0 as compared to all the blends of cotton seed biodiesel. At full load condition, the BSEC is lowest for B0 and higher for

B20. It has been observed that with the increase in load, the brake specific energy consumption was found to be lower. This is because the higher fuel inlet temperature results in lower viscosity which causes better atomization and subsequent better combustion. This results in lower brake specific energy consumption.

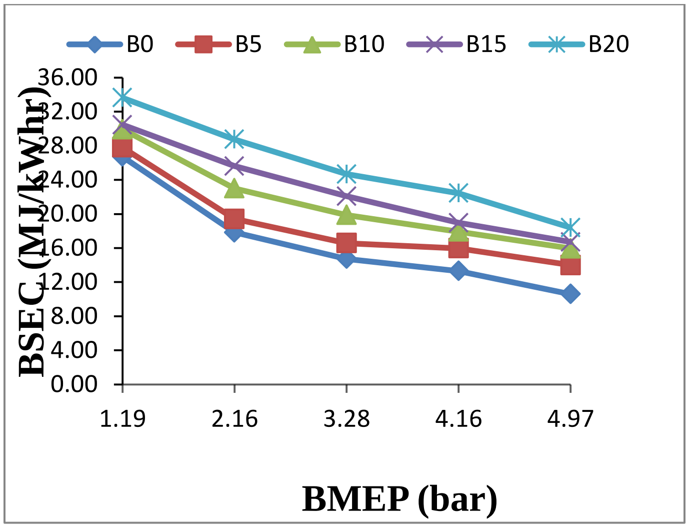

Fig BSEC versus BMEP graph

EMISSION CHARACTERISTICS

The emission characteristics of various blends of Cotton Seed oil biodiesel and diesel are summarized in this section. Main exhaust emissions are CO, UBHC, NO_x and CO_2.

CO EMISSIONS

The variation of carbon monoxide (CO) emission of blends of diesel and Cotton Seed oil biodiesel is shown in Figure. The CO emissions are found to be increasing with increase in load since the air-fuel ratio decreases with increase in load such in internal combustion engines. The engine emits less CO using biodiesel blends as compared to that of diesel fuel under all loading conditions. With increasing biodiesel percentage, CO emission level decreases as amount of oxygen content in biodiesel helps in complete combustion and proper oxidation. The higher cetane number of blend as compared to that of mineral diesel is also one of the reasons of better combustion. For the experimental investigation it has been found that B20 has lowest CO emission than other blends and baseline diesel fuel. At part load condition variation in CO emission for all the blends and baseline diesel is insignificant. At part load, the value of CO emission for B5, B10, B15 and B20 were 0.53, 0.51, 0.42 and 0.40 whereas the CO emission for diesel was 0.61.

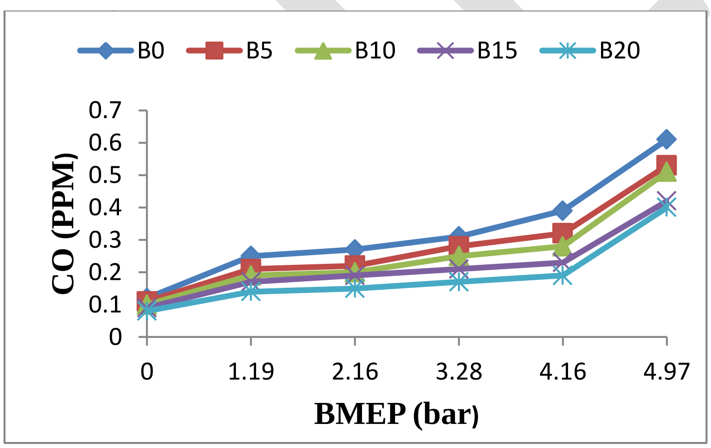

Fig CO versus BMEP

CO_2 EMISSIONS

The variations of CO_2 emissions of different fuels from the engine are shown in figure. In the range of whole engine load, the CO_2 emission of diesel fuel was lower than that of the other fuels. This is because vegetable oil contains oxygen element; the carbon content is relatively lower in the same volume of fuel consumed at the same engine load, consequently the CO_2 emissions from the vegetable oil and its blends are lower but with increase in temperature of Cotton Seed oil, combustion inside the cylinder becomes better. This better combustion results in increased value of CO_2. At part load, the values of B5, B10, B15 and B20 were 6.1, 5.3, 4.9 and 3.1 whereas the value of diesel was 7.2 for CO_2.

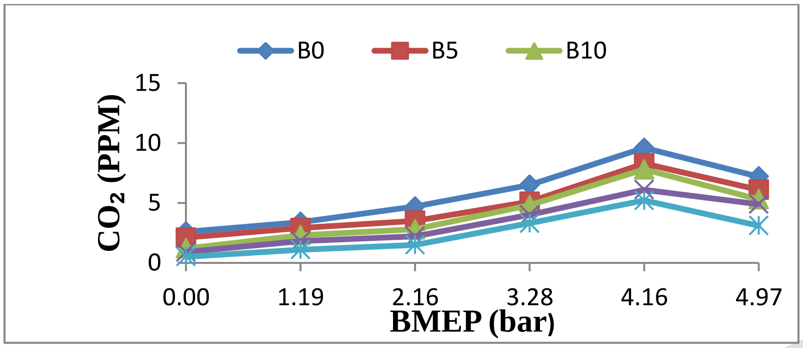

Fig CO_2 versus BMEP

UN-BURNT HYDRO CARBON EMISSIONS

Unburnt hydrocarbon emissions for different blends are shown in fig. It was found that the HC emissions were lower for all the blends of cotton seed oil biodiesel. HC emissions decrease with the increase percentage of biodiesel in the blends. B20 has minimum hydro-emissions at full load conditions i.e. 31.83 as shown in figure. At part load conditions HC emissions of the diesel was 10% to 20% more than the cotton seed oil biodiesel. The significant decrease in HC emission was due to the complete combustion of the fuel.

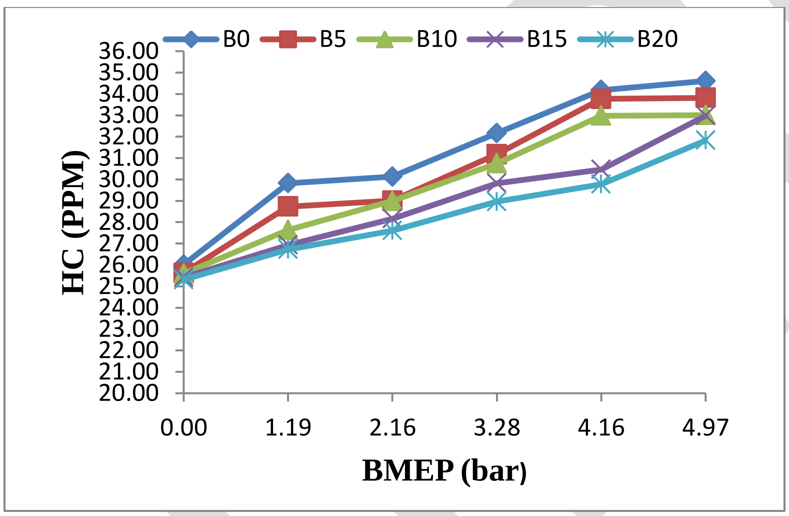

Fig HC versus BMEP

NO_x EMISSIONS

The NO_x values as parts per million (ppm) for different fuel blends of diesel and B20 in exhaust emissions are plotted. The amount of NO_x produced at peak load condition for B5, B10, B15 and B20 and B0 were 1600, 1681, 1791, 1854 and 1553 respectively. It can be seen that the increasing proportion of biodiesel in the blends was found to increase NO_x emissions slightly when compared with that of pure diesel (B0). This could be attributed to the increased exhaust gas temperatures and the fact that biodiesel had some oxygen content in it which facilitated NO_x formation. In general, the NO_x concentration varies linearly with the load of the engine.With increasing load, the temperature of the combustion chamber increases and NO_x formation is enhanced because NO_x formation is strongly dependent on the temperature.

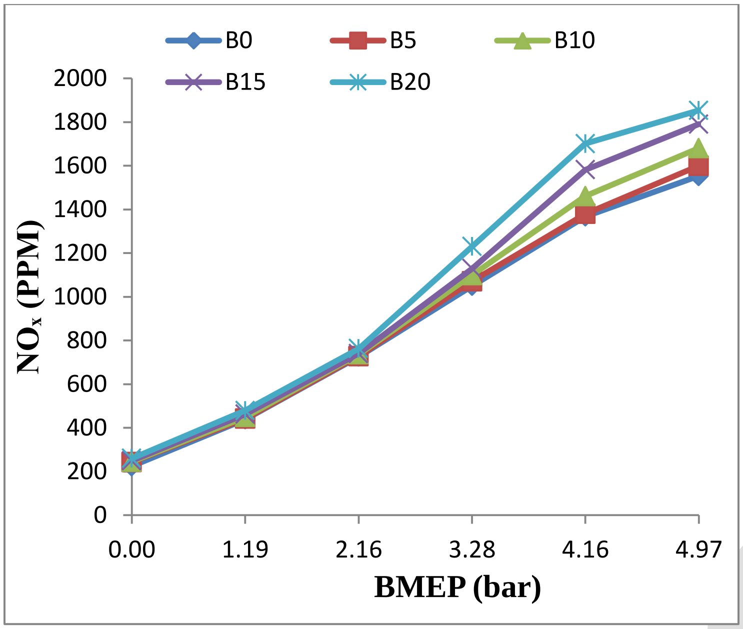

Fig NO$_x$ versus BMEP

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CONCLUSIONS

The experiments were conducted using blends of Cotton Seed oil methyl ester and diesel. Subsequently combustion, performance, and emission studies were carried out. Based on the experimental results, the following major conclusions have been drawn:

1. Full load brake thermal efficiency was found to decrease with increase in COME percentage in the blend due to lower heating value of biodiesel. Full load BTE of B5 was found very near to baseline data of diesel i.e. 25.82%.
2. Brake specific energy consumption of 10.60 MJ/kWh was observed for diesel at full load. With increase in percentage of COME in the blend, a steady increase in BSEC was observed
3. Carbon monoxide was found to get reduced with increase in COME percentage in the blends. At part loads, CO emission was found to be low for all the test fuels, however, substantial increase was observed after 60% load. Reduction in carbon monoxide emissions for higher blends may be attributed to improved combustion of high cetane and oxygenated fuel such as COME.
4. Hydrocarbon emissions were found to decrease for all the blends of Cotton Seed oil methyl ester compared to neat diesel fuel confirming better combustion characteristics.
5. Due to higher cetane rating of COME and improved combustion, the in-cylinder temperature was increased resulting in higher NOx emission for blended fuels as compared to baseline data. Full load NOx emission was steeply increased by 23% for B20 as compared to diesel baseline. Lower blends exhibited marginal increase in NOx emissions.

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