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International Journal of Engineering, Science and Technology
Vol. 2, No. 6, 2010, pp. 142-149

INTERNATIONAL JOURNAL OF ENGINEERING, SCIENCE AND TECHNOLOGY
www.ijest-ng.com

Optimization of injection pressure for a compression ignition engine with cotton seed oil as an alternate fuel

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Abstract

The major problem with the direct use of vegetable oils as fuel into CI engines is their higher viscosity. It interferes the fuel injection and atomization and contributes to incomplete combustion, nozzle clogging, excessive engine deposits, ring sticking, producing thick smoke, etc. The problem of higher viscosity of vegetable oils can be overcome to a greater extent by various techniques, such as heating of fuel lines, trans-esterification, modification of injection system, etc. In the present investigation, short term tests were conducted with the use of untreated cotton seed oil in a single cylinder, four stroke, and direct injection diesel engine. Tests were conducted with cotton seed oil and diesel. To improve the combustion characteristics of cotton seed oil in an unmodified engine, effect of increase in injection pressure was studied. The injection pressure was increased from 180 bar to 240 bar (in steps of 15 bar). The investigation revealed that the optimum pressure for cottonseed oil as 210 bar and comparison of the performance of the engine was studied in terms of brake specific fuel consumption, brake thermal efficiency, indicated thermal efficiency, mechanical efficiency and exhaust emissions.

Keywords: Cotton seed oil; CI Engine; Injection pressure; performance characteristics; alternate fuels

1. Introduction

The physical, combustion and auto ignition properties of vegetable oils are almost similar to those of diesel fuels and hence can be used in diesel engines with little or no engine modifications. However, high viscosity and low volatility being inherent properties of most of such vegetable oils produced from plants (seeds), constraining their direct use in engines without any modifications. High viscosity interferes with fuel jet penetration, atomization and produces thick smoke in the exhaust. Therefore, the vegetable oils are not ideally suited as fuels for diesel engines; they are to be modified to bring closer to diesel oil in their properties.

Investigations have been carried out on a variety of vegetable oils like jatropa oil, karanj oil, rice bran oil, rapeseed oil etc in diesel engines. Diesel engines with vegetable oils as fuels produce the same power output but reduced thermal efficiency and increased emissions. The particulate emissions of vegetable oils are higher than that of diesel fuel with lower value of NO_x emissions. However, their performance is slightly inferior to diesel (Agnes *et al.,* 2007; Raja *et al.,* 2003; Jeffrey and Nancy, 2009). Investigations were carried out to study the effects of vegetable oil fuels and their methyl esters (raw sunflower oil, raw cottonseed oil, raw soybean oil and their methyl esters, refined corn oil and refined rapeseed oil) on a direct injection, four stroke and single cylinder diesel engine (Altin *et al.,* 2001). They concluded that raw vegetable oils can be used as fuel in diesel engines with some modifications and when compared to diesel fuel, a little amount of loss in power was observed and the particulate emissions were higher than that of diesel fuel. Vegetable oil methyl esters exhibited the performance and emission characteristics closer to the diesel fuel. The physical, chemical and fuel related properties of tobacco seed oil were investigated and suggested that this non edible oil may be an appropriate substitute for diesel fuel. Investigations on tobacco seed oil suggested that this non edible oil may be an appropriate substitute for diesel fuel (Giannelos *et al.,* 2002).

The use of vegetable oils in diesel engines was studied by Nazar *et al.* (2004). Experiments were conducted to access the suitability of karanj and coconut oils as fuels in a diesel engine, and concluded that, for short term tests coconut oil and karanj oil can be directly used in diesel engines without any engine modifications. Almost same power output was noticed with slightly reduced thermal efficiency with coconut oil and karanj oil when compared with diesel. Both HC and CO emissions were found high for vegetable oils under normal operating conditions.

Review on the use of vegetable oils as fuels for internal combustion engines was conducted (Bhattacharyya and Reddy, 1994). They reported that the major difference between diesel fuel and vegetable oil included, for the later, the significantly higher viscosities and moderately higher densities, lower heating values, rise in the stoichiometric fuel/air ratio due to the presence of molecular oxygen and the possibility of thermal cracking at the temperatures encountered by the fuel spray in the naturally aspirated diesel engines. These differences contribute to the poor atomization, coking tendencies, carbon deposition and wear that generally experienced and which adversely affect the durability of the engine. Injection timing and proper ratio of vegetable oil and diesel in the blend were found to be critical in determining the proper atomization. The gathered information indicates a better performance of sunflower, soybean and rapeseed oil relative to the other oils, both in terms of durability and thermal efficiency and power output.

Effect of injection pressure has been investigated to use Jatropa Curcas oil in diesel engine and observed that there was a slight improvement in the performance of engine with increase in injection pressure (Srinivasa *et al.,* 1997). The production of biodiesel by two-step esterification was done using rubber seed oil with acid catalyst (Ramadhas *et al.,* 2005). Transesterification with methanol and characterization of vegetable oils and their methyl ester as the substitute of the petroleum fuel and future possibilities of Biodiesel production were reviewed (Singh and Singh, 2010). Methanol along with jatropa oil was used in a CI engine in dual fuel mode operation. Methanol was carbureted with different jet openings and was observed that rate of pressure rise and peak pressures were high with jatropa oil operation. However, with the methanol induction in the dual fuel mode, the rate of pressure rise and peak pressure was reduced considerably. The effect of supercharging on the performance of diesel engine with cotton seed oil was studied (Amba and Rama, 2003). The performance improved with increase in NO_x emissions. The experiment that for biodiesel mixtures, CO emission was lower than that of diesel fuel (Nabi *et al.,* 2008). Compare to neat diesel fuel, 30% biodiesel mixtures reduced CO emissions by 24%. CO emitted by all biodiesel blends is lower than the ones for the corresponding diesel fuel case. This reduction in CO increases as the percentage of biodiesel in the blend increases (Rakopoulos *et al.,* 2008, Gattamaneni *et al.,* 2008; Ghobadian *et al.,* 2009). When biodiesel is used as fuel at all loads there was a reduction in CO emission (Usta *et al.,* 2005). At low concentration of the biodiesel in the blend, the inbuilt oxygen helps in complete combustion of the fuel. But high concentration of biodiesel increases the viscosity of the fuel and there is a slight increase in the specific gravity. This causes poor atomization of biodiesel which results in poor combustion of fuel; suppresses the complete combustion process and as a result the emission of CO increases (Makareviciene *et al.,* 2003; Suresh *et al.,* 2008).

The effect of injector opening pressure on the performance of a jatropha oil fuelled compression ignition engine, the optimum injection opening pressure was found out for jatropha oil and comparison of performance, emissions and combustion parameters were made with diesel (Narayana and Ramesh, 2004). Increasing the injection pressure lead to a significant reduction in smoke level, HC emissions and also improved the brake thermal efficiency.

Experimental investigations were carried out varying different parameters to optimize the production of biodiesel using methanol as catalyst (Siva *et al.,* 2009). The optimum conditions for biodiesel production are suggested i.e. a maximum of 76% biodiesel was produced with 20% methanol in presence of 0.5% sodium methaoxide. Thermal efficiency with biodiesel mixtures was slightly lower than that of neat diesel with reduced CO, PM, smoke emissions. While 10% BD mixtures reduced PM, smoke emission by 24% and 14% respectively. With 30% biodiesel blend, they observed reduction in CO emission by 24% and 10% increase in the NOx emission duel to the presence of oxygen in their molecular structure.

Experimental studies were carried out on the performance of castor non-edible vegetable oil and its blends with diesel on a single cylinder, 4 stroke, naturally aspirated, direct injection, water cooled, eddy current dynamometer Kirloskar Diesel Engine at 1500 rpm for variable loads (Naga *et al.,* 2009). It is observed that 25% of neat Castor oil mixed with 75% of diesel is the best suited blend for Diesel engine without heating and without any engine modifications. The Brake Thermal Efficiency, BSFC of castor oil are 33.45% lower and 54.76% higher, while CO, UHC, smoke are 56.41%, 20.27%,31.32% respectively higher and NOx are 44% lower compared to those of diesel. This is due to incomplete combustion of the fuel and delay in the ignition process.

As an effective solution for improving performance and emission characteristics of CSO biodiesel blends with petrodiesel, coating of combustion chamber parts such as surfaces of cylinder, head, piston, inlet and exhaust valves with a ceramic material was introduced in single cylinder DI CI engine and the performance such as engine power and SFC; emission values such as CO and smoke of the CSO blends with diesel (B20 and B40) were improved (Hazar, 2010). The study for the effect of preheated CSO biodiesel on performance and exhaust emission of CI engine (Karabektas *et al*. 2008) and reported that optimum preheating temperature of CSO biodiesel was 90 °C due to favorable effects on BTE and CO emissions. However, this biodiesel caused higher NOx emissions. The studies related to neat CSO and diesel fuel blends were conducted by (Fontaras *et al.,* 2007) a common rail Euro 3 compliant diesel engine was tested with CSO blends. They concluded that 10% CSO and 90% diesel blends can be applied in common rail diesel engine without impacts on operation and emission seven though proper idle engine management is required. However, the engine suffered from misfuelling at low ambient temperatures (Fontaras *et al.,* 2007). In addition, NOx appear to increase slightly in some cases.

Different parameters for the optimization of biodiesel production were investigated and suggested that a maximum of 77% biodiesel was produced with 20% methanol in presence of 0.5% sodium hydroxide. The engine experimental results showed that exhaust emissions including carbon monoxide (CO) particulate matter (PM) and smoke emissions were reduced for all biodiesel mixtures, but a slight increase in oxides of nitrogen (NOx) emission was experienced for biodiesel mixtures (Nurun *et al.*, 2009). The application methods of jatropha oil as a substitute for CI engine gave the lower brake thermal efficiency and higher specific fuel consumption compared to diesel fuel operation and compared with seven different oils. It was reported that a diesel engine without any modification would run successfully on a blend of 20% vegetable oil and 80% diesel fuel without damage to engine parts (No, 2010). Dual fuel mode operation using coir-pith derived producer gas and rubber seed oil as pilot fuel was analyzed for various producer gas–air flow ratios and at different load conditions and observed that specific energy consumption was high along with exhaust emissions and it suitable for stationary engine application, particularly power generation (Ramadhas *et al*., 2008).

It is required to conduct the research about the exhaust emission characteristics of LSO biodiesel blends in diesel engine. In the test of single cylinder, DI CI engine that has a rated output of 4.4 kW at 1500rpm, the experimental results showed that the optimum fuel injection pressure was 24MPa with LO biodiesel (Puhan *et al*., 2009). At this optimum pressure, the thermal efficiency was similar to diesel and a reduction in CO, HC and PM with an increase in NOx was noticed. The combustion analysis showed that the ignition delay was lower at higher injection pressures compared to diesel. Performance studies were carried on cottonseed oil and diesel blends and observed that, there was about 3.7% decrease in BSFC, 6.7% increase in mechanical efficiency, 1.7% increase in brake thermal efficiency, and 21.7% decrease in smoke density with CSO10D90 blend as compared to that of neat diesel operation, and performance of other blends and straight vegetable CSO was inferior to conventional diesel (Murali and Mallikarjuna, 2009).

Keeping the above points in view, a study was undertaken to investigate the performance characteristics of cotton seed oil and diesel fuel at different injection pressures without any major engine modifications on the engine.

2. Experimental Setup

A single cylinder direct injection type, 4 stroke, water cooled vertical diesel engine developing 3.5 kW at 1500 rpm is coupled with rope brake dynamometer for experimentation purpose. The dynamometer consists of a pulley coupled to the engine as shown in Figure 1. A thick rope is wound around the pulley. One end of the pulley is connected to lead screw that can be rotated by wheel mounted on it and other end is connected to a spring balance. Load can be applied by rotating the wheel. As the rope is tightened around the pulley, engine is loaded and the spring balance shows the load in kg. Control panel consists of engine speed indicator which indicates the speed of engine in RPM. Fuel consumption was measured by a glass burette mounted on the control panel. Exhaust emissions and smoke were measured with 2- Gas Analyser model EGA 1000/2 and Diesel Smoke Meter model DSM 2000. The different physical properties of cotton seed oil, procured for the purpose of experimentation were determined in the laboratory. Specific gravity and gross calorific values are determined with hydrometer and Bomb calorimeter respectively.

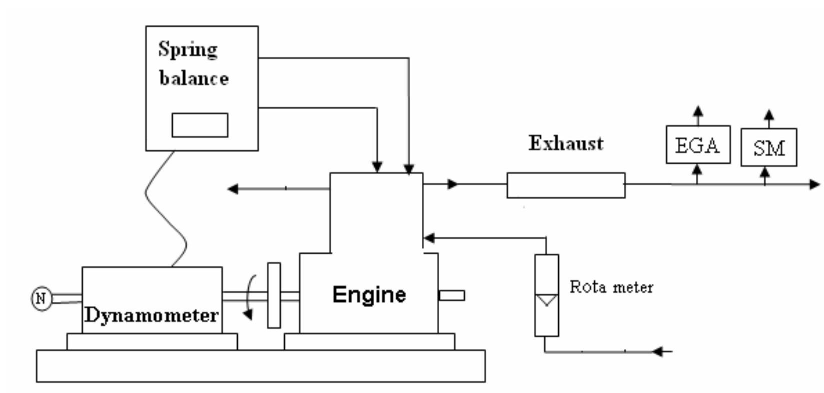

Figure 1: Experimental set up

2.1 Experimentation: Experiments were conducted with diesel and cotton seed oil under naturally aspirated conditions with increased injection pressures from 180 bar to 240 bar (in steps of 15 bar). Table 1 and Table 2 show the specifications of the engine and the properties of the fuels respectively.

Table 1: Specifications of the engine:

Type	Dimensions
Make	Komet
Type	Single cylinder, Four stroke, Vertical Diesel engine 5H.P. (3.5kW) at 1500 rpm
Dynamometer	rope brake
Cooling	Water cooling
Charging	Naturally aspirated
Bore	80 mm
Stroke	110 mm
Diameter of pulley	360 mm

Table 2: Properties of Fuels

Property	Diesel	Cotton seed oil
Density (kg/m^3)	850	912
Calorific Value (kJ/kg)	43400	39500
Kinematic Viscosity (cSt @40°C)	3.5	55.6
Flash Point (°C)	68	205
Fire Point (°C)	107	228

3. Results and Discussion

Initially the engine was run with diesel to know the performance at 180 bar injection pressure as specified by the manufacturer specified and the injection pressures were increased from 180 bar to 240 bar (in steps of 15 bar). Further experiments were conducted with cotton seed oil and diesel. The performance of the engine with different blends of cotton seed oil and diesel at different injection pressures was studied.

3.1 Brake Specific Fuel Consumption: From Figure 2 it may be observed that as the load on the engine increases brake specific fuel consumption decreases. The injector was set for different opening pressures namely 195 bar, 210 bar, 225 bar and 240 bar and the engine was tested. A glance on the figure reveals that BSFC decreases with increase in brake power. This may be due to good atomization at higher injection pressure which helps in faster rate of heat release.

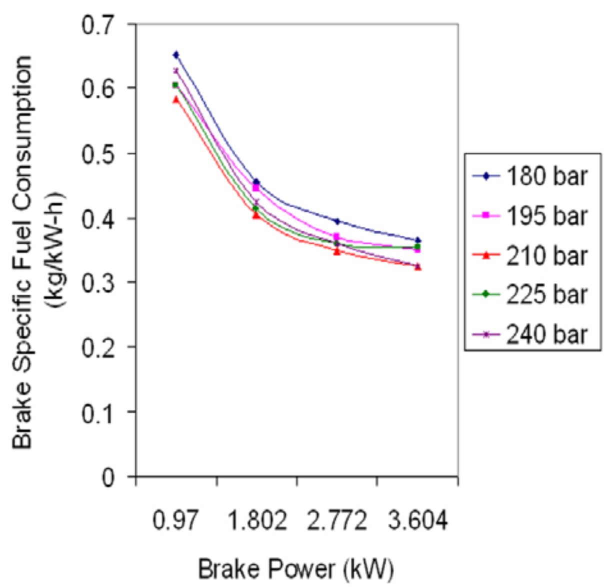

Figure 2: BSFC vs. BP

3.2 Brake Thermal Efficiency: From Figure 3 the brake thermal efficiency is observed to be highest at 210 bar injection pressure. Increasing the injection pressure leads to better spray atomization particularly at the beginning and end of injection. Since injection always takes place at high pressures; when the injection opening pressure is raised, the atomization is better. This leads to better performance. Between 210 and 225 bar there seems to be no significant difference. The highest pressure of 240 bar deteriorates the performance, probably due to reasons

1. Improper combustion.
2. Very fine droplets of fuel have less momentum.

The brake thermal efficiency increases from 25.01% to 28.02% when the injection pressure is raised from 180 bar to 210 bar at full load. The increase in the brake thermal efficiency also means that less fuel is injected for the same output.

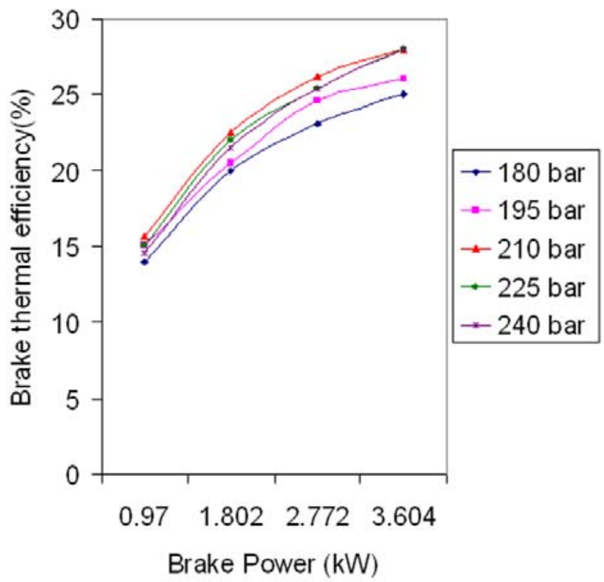

Figure 3: Brake thermal efficiency vs. BP

3.3 Unburnt Hydrocarbons: The level of unburnt hydrocarbon emissions is shown in Figure 4. As the opening pressure increases the HC emissions are reducing because, higher injection opening pressures will lead to a proper spray while the injection starts. This will enhance the performance with vegetable oils as they have a high viscosity. This is probably because of the improvement in the spray, which can lead to a lower physical delay. The improved spray also leads to better combustion and thermal efficiency.

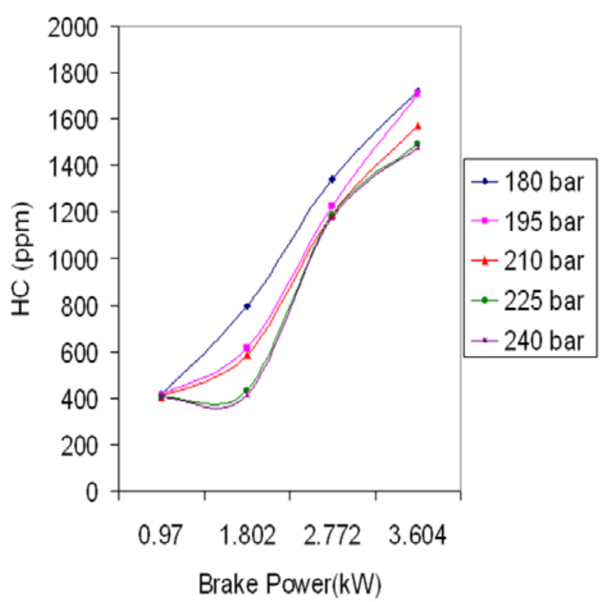

Figure 4: HC emissions vs. BP

3.4 Smoke Levels: From Figure 5 it can be concluded that the smoke level decreases with increasing the injector opening pressure due to better atomization of fuel due to rise in the injection pressure leading to better combustion.

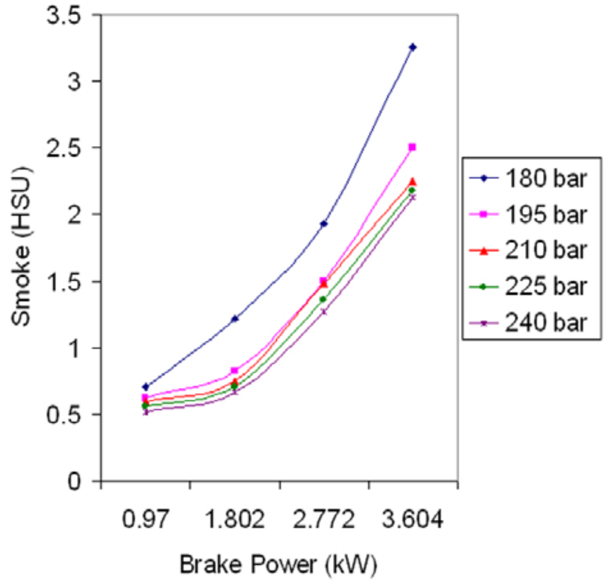

Figure 5: Smoke vs. BP

4. Conclusions

The following conclusions are drawn based on the experimental work. Increased injection pressure has a significant effect on enhancing engine performance and lowering emissions. Increase in the injection pressure from 180 bar to 240 bar with cotton seed oil as fuel lead to:

1. Quieter operation of the engine is observed when cotton seed oil is used as fuel.
2. Performance of engine with cotton seed oil as fuel is better at an IP of 210 bar.
3. An increase in the Brake thermal efficiency from 25.02% to 28.02% was observed with increase in injection pressure from 180bar to 210 bar; due to better atomization and improved combustion of the fuel.
4. Lowering of the HC emissions from 1720 ppm to 1480 ppm.
5. Performance of engine with cotton seed oil as fuel at an IP of 210 bar is approximately similar to the operation of engine with diesel.

In the present investigation, short term tests were conducted with the use of untreated cotton seed oil in a single cylinder, four stroke, and direct injection diesel engine. To improve the combustion characteristics of cotton seed oil in an unmodified engine, effect of increase in injection pressure was studied. The injection pressure was increased from 180 bar to 240 bar (in steps of 15 bar) which is limited to a certain extent.

Future work may be extended to:

- 1000 hrs durability tests may be conducted on diesel engines and the wear associated with the engine moving parts may be analyzed
- Increase in injection pressures in steps of 5 bar may be attempted
- Instead of modifying the existing engine, new designs of engines may be attempted keeping in mind comprehensive combustion optimization
- The studies on future biodiesel and biodiesel – diesel blends fuels may be carried out in order to reduce the viscosity of non-edible vegetable oils

Nomenclature

BSFC	Brake specific fuel consumption, kg/kWh
BP	Brake power (kW)
HC	Hydrocarbon emissions (ppm)
HSU	Hatridge smoke unit (HSU)

IP Injection pressure (bar)
RPM Revolutions per minute (rpm)

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Received June 2010
Accepted August 2010
Final acceptance in revised form October 2010