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Experimental Investigation of Performance and Emission Characteristics of Coated Squish Piston in a CI Engine Fueled With Vegetable Oil

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In this study, the performance and emission characteristics of the CI engine using coated squish piston fueled with Jatropha oil is investigated experimentally. The obtained results were compared with the conventional piston. The test was conducted in single cylinder naturally aspirated water cooled direct injection diesel engine. The squish head and Partially Stabilized Zirconia coating was provided in the conventional piston bowl which helps in better turbulence, i.e., better mixing of air and fuel mixture resulting in improved combustion with the reduced emissions. Because of improved combustion, the peak cycle temperature in the combustion chamber increases. This increase in peak cycle temperature helps in better atomization and vaporization of the fuel used, i.e., Jatropha biodiesel. The increase in the combustion chamber temperature reduces the viscosity of the Jatropha biodiesel resulting in improved combustion. The performance and emission characteristics were improved much better with the squish piston when compared with the conventional piston. Improved brake thermal efficiency was obtained with the coated squish piston. Emissions like HC, CO and Smoke was considerably reduced with the coated squish piston. But in turn, NO_X and CO_2 are increased due to the increase in peak cycle temperature inside the combustion chamber.

Keywords: PSZ, Conventional Piston, Jatropha oil, Squish piston, Transesterification.

Introduction

Fossil fuels are non‐renewable resources which takes millions of years to go. Also they are depleted at faster rate than they are generated. The increase in number of vehicles shows the demand for fuel. Thus, fossil fuels will become more scarcity and more expensive in the future. Due to the scarcity, the prices of fossil fuels are hiking at faster rate. Moreover, there is number of drawbacks of using fossil fuels such as atmospheric pollution and environmental issues. The emissions from the fossil fuel combustion are major contributor of greenhouse gases which may lead to global warming. The emissions (like HC, CO, CO_2, NO_X, SO_X, Particulates and Carcinogenic compounds) from the combustion of fossil fuel, are the major sources of air pollutants that affect the air quality standards in the atmosphere. Thus many researchers find alternative sources of renewable energy to tackle these problems, i.e., drawbacks and shortage of fossil fuels.

Biodiesel is one of the most superior sources of renewable energy. It is bio‐degradable and it is derived from sources like vegetable oil, animal fat, etc. The properties of biodiesel are very much closer to the properties of diesel fuel, i.e., there is no need of any modifications in the already existing engines for using these fuels. Biodiesel is defined as the fuel comprising of mono‐alkyl esters of long chain fatty acids derived from vegetable oil or animal fat. Biodiesel has several advantages as compared to conventional diesel fuel. The advantages of biodiesel are: (1) comes from renewable sources (2) biodiesel production is more efficient as it does not need mining, refineries, etc. (3) reduced emissions (4) no engine modification (5) diesel engine performs better on biodiesel due to high cetane number (6) high purity of biodiesel eliminates the use of lubricant.

The main sources for biodiesel production are vegetable oil, animal fat and waste cooking oil. Vegetable oil can be classified into two types namely, edible oils and non‐edible oils. Edible oils like palm oil, peanut oil, rapeseed oil, sunflower oil, coconut oil, olive oil, and soya bean oil, etc have become major sources for biodiesel production. But edible oils may become more expensive due to the competition between human consumption and biodiesel market. To overcome this drawback, non‐edible oils are introduced for biodiesel production. Some of the non‐edible oils available in the in the market are Jatropha, Pongamia (Karanja), Mahua, Linseed,

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Table 1ð Comparison of Properties of fuels

Properties	Diesel	Raw Jatropha oil	Esterified Jatropha oil
Density at 15°C (kg/m^3)	830	910	884
Calorific Value (kJ/kg)	44.9	39.4	40.566
Viscosity (cSt)	3.38	30	5.42

Cottonseed, Neem, Castor, Polanga, Jojoba, See mango, Tomato seed, Rubberseed, Tobacco seed, Desert date, Cardoon, Poon, Pilu, Ethiopian mustard, etc. Out of these, only thirteen non ï edible oils are selected and analyzed in terms of fuel properties with the diesel properties and found that they are more suitable to be used as alternative for diesel fuel. Among these non ï edible oils, Jatropha and Pongamia are best suitable to be used under cold weather conditions when compared to others.

Jatropha

Jatropha (*Jatropha Carcus*) belongs to the *Euphorbiaceae* family. The origin of Jatropha plant is American tropics but it is found in tropical and subtropical countries, like sub-Sahara Africa, India, South East Asia, and China. The name comes from the latin words *Jatros* (Doctor) and *Trophe* (Food) as it has many medicinal and industrial use. Jatropha plant can produce significant oil content of approximately 40% of the seed content. Once the plant stars flowering, the seed starts maturing after 3ï 4 months and it will continue producing seeds for 50 years.

Jatropha plant is highly adaptable to various types of soils including sandy and saline soils. Because of its leaf-shedding activity, decomposed shed leaves would provide nutrients for the plant and reduces water loss. Jatropha plant can withstand wide range of climate and rainfall but cannot grow in waterlogged areas. In India like countries lot of un-cultivating lands are available because of the scarcity of water sources. It can be effectively used for cultivate Jatropha plants. Jatropha plant is a drought-resistant plant and also Jatropha cultivation helps in regaining of soil nutrients. Raw Jatropha oils are much more viscous, are much more reactive to oxygen, and have higher cloud point and pour point. The Esterified Jatropha oil offer lower engine noise, and lower smoke, HC, and CO and higher thermal efficiency. The properties of diesel fuel and Jatropha oil fuel are compared in the Table 1.

Squish Piston

Squish is defined as radially inward or transverse gas motion that occurs towards the end of the compression stroke when a portion of a piston face and cylinder head approach each other closely. The amount of squish is defined by percentage squish area, i.e., percentage of the piston area, which closely approaches the cylinder head. Squish head in the piston bowl helps in improving the turbulence, i.e., better mixing of air and fuel mixture, resulting in improved combustion with reduced emissions.

Coated Squish Piston

The diesel engine rejects about two third of the heat energy of the fuel through the coolant and exhaust, leaving only about one third as useful power output. If the heat rejected could be reduced, then the thermal efficiency would be improved. To increase the efficiency of IC engines and generate higher combustion chamber temperatures, low heat rejection concept is investigated. Low Heat Rejection engines aim to reduce the heat lost to the coolant.

The diesel engine with its combustion chamber walls insulated by ceramics is referred to as Low Heat Rejection (LHR) engine. The components that are normally insulated include piston, cylinder head, valves, cylinder liner, exhaust ports, etc. Insulation is done by coating the top surface of the piston bowl in which squish head was already made. Partially Stabilized Zirconia was used for coating. The coating was carried out by Plasma Spray coating technique. The spraying parameters are very important in determining the reliability of the coating. 0.3mm of PSZ was coated on the top surface of the piston bowl. In LHR engine, shorter ignition delay, due to the higher surface temperature, improves the atomization and vaporization, thus leading to a decreased premixed phase of combustion with the increased diffusion phase of combustion thereby complete combustion was ensured.

Experimental setup

Transesterification

In CI engines, the raw vegetable oil can be used as biodiesel in four main categories namely direct use of vegetable oil, micro ï emulsions, thermal cracking and Transesterification. The direct use of vegetable oil results

Table 2ð Engine Specifications

Make	SPEED WEL
Power	8HP (5.9 kW)
Speed	1500rpm
No. of cylinder	1
Bore	95mm
Stroke	110mm
Compression ratio	16:01
Cubic capacity	780cc
Cooling system	Water cooling

in incomplete combustion. It was due to the very high viscosity and specific gravity of the vegetable oil. The micro ï emulsions and thermal cracking shows incomplete combustion because of lower cetane number and energy content. Transesterification is the simplest biodiesel production method to convert raw vegetable oil into biodiesel. The biodiesel properties closely match with the diesel properties. Thus transesterification is chosen for biodiesel production.

Transesterification is the process of reacting triglyceride molecules of vegetable oil with esters of alcohol in the presence of catalyst such as KOH, NaOH, etc to produce mono alkyl esters of fatty esters like glycerol and fatty acids. The mixture of fatty esters produced by this reaction is referred as biodiesel.

Experimental Arrangement

The arrangement requires the following systems and apparatus for carrying out the desired equipment.

(1) Diesel engine
(2) Eddy current dynamometer
(3) Exhaust five gas analyzer
(4) Smoke meter
(5) Fuel metering system

The engine used for this experiment was a single cylinder naturally aspirated water cooled direct injection diesel engine. An eddy current dynamometer has coupled to the engine and it was used to load the engine. The test engine and eddy current dynamometer are mounted on the channels which are embedded on concrete foundation. The fuel consumption is measured in burette which is filled with the fuel used. The five gas analyzer and Smoke meter are used to measure the engine exhaust. The engine specification is listed in Table 2.

The exhaust five gas analyzer was used to measure the exhaust gas composition. It was used to measure the exhaust emissions like HC, CO, CO_2, O_2 and NO_x. The exhaust gases are measured by Crypton five gas analyzer in which HC is analyzed by Flame Ionization Detector (FID), CO and CO_2 are analyzed by Non ï Dispersive Infra ï Red analyzer (NDIR), NO_x was measured by Chemiluminescence Detector (CLD). Smoke emission was measured by Hartridge type Smoke meter.

Result and discussion

The experiment was conducted on the single cylinder, naturally aspirated, water cooled, direct injection diesel engine. The test engine was started and allowed to run for five minutes to reach the lubricating oil temperature as 80º C. Initially, the time taken for 10cc fuel consumption and various emissions were recorded with the base engine. The same experiment was repeated for ensuring the repeatability of the readings. After that, the test engine piston was replaced and tested with squish piston. In the next test the squish piston was coated with PSZ to improve the atomization and combustion parameters. In all the cases the measurements were carried out for the conventional fuel and for the bio-diesel. The results using both the conventional piston squish piston and coated squish piston engine for the conventional fuel and for the jatropha fuels were discussed below:

A Performance Effect of brake load on brake thermal efficiency

The brake thermal efficiency of Jatropha biodiesel is lesser than the diesel fuel for both conventional piston and squish piston when compare with coated squish piston. It was due to the lower calorific value, high specific gravity and high viscosity of the Jatropha biodiesel causes the longer ignition delay and incomplete combustion. The maximum brake thermal efficiency for Jatropha biodiesel using coated squish piston is 27.79% which is 6.7% higher when compared with the conventional piston.

Emission Effect of Brake Load on Hydrocarbon Emission

The effect of brake load on hydrocarbon (HC) emission was discussed in Figure 1, for the conventional piston, squish piston and coated squish piston fueled with diesel and Jatropha biodiesel. Piston, squish piston and coated squish piston fueled with diesel and Jatropha biodiesel. The HC emission was lesser for the Jatropha biodiesel than that of diesel fuel. It was due to the higher oxygen content of the Jatropha biodiesel that enhances the post combustion reactions. The HC emission reduces with the squish piston than the conventional piston when fueled with Jatropha biodiesel. This is due to the better mixing of air and fuel mixture resulting in improved combustion. Hence the peak cycle temperature increases

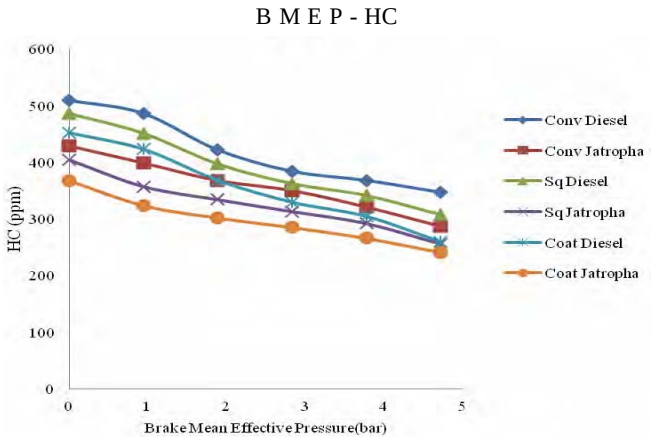

Fig. 1ð Effect of unburned hydrocarbon emission with respect to Brake Mean Effective Pressure

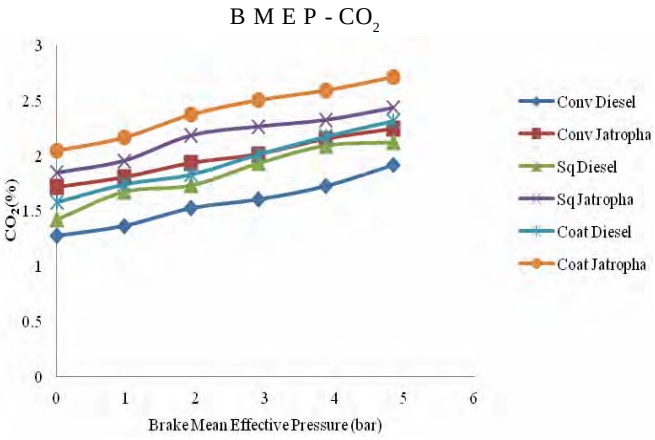

Fig. 2ð Effect of carbon dioxide emission with respect to Brake Mean Effective Pressure

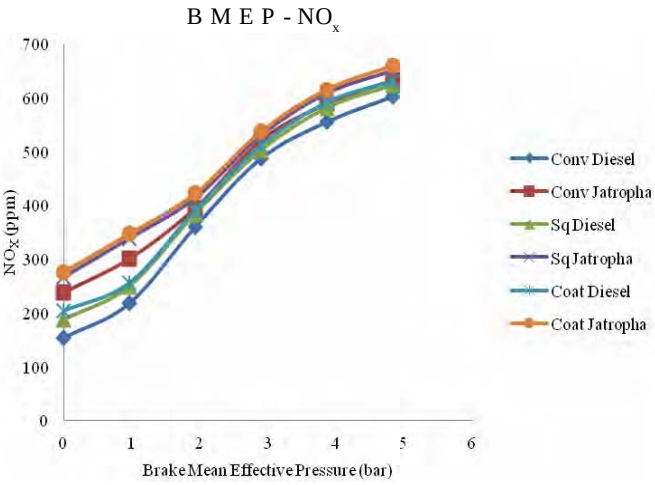

Fig.3ð Effect of Oxides of Nitrogen with respect to Brake Mean Effective Pressure

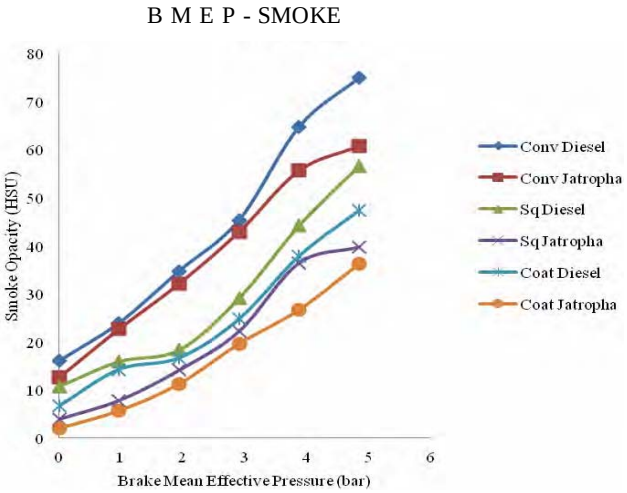

Fig. 4ð Effect of Smoke Emission with respect to Brake Mean Effective Pressure

which helps for better atomization and vaporization of the Jatropha biodiesel. At full load conditions, the HC emission was reduced by 10.8% and 16.03% for the squish piston and for coated squish piston respectively when compared with the conventional piston.

Emission Effect of Effect of brake load on carbon dioxide

The effect of engine load on carbon dioxide (CO_2) emission has shown in Figure 2. The carbon dioxide emission increases with the increase of brake power. This is due to excess availability of oxygen content in the Jatropha biodiesel and the combustion chamber temperature due to the squish and thermal barrier coating enhances the combustion. At full load operation, the carbon dioxide emission for squish piston and coated squish piston is higher than the conventional piston by 7.82% and 17.34% respectively.

Emission Effect of Effect of brake load on NO_x emission

Figure 3 shows the effect of NO_X emission with respect to load. Oxides of Nitrogen are produced mainly due to the cycle temperature. NO_X emission increases for the squish piston and for the coated squish piston for all the fuels. The squish piston and coated squish piston increases the cycle temperature due to the less heat transfer to the surrounding. At full throttle condition, NO_X emission from the combustion of the Jatropha biodiesel using squish piston and coated squish piston is increased by 2.76% and 3.95% respectively when compared with the conventional piston.

Emission Effect of Effect of brake load on smoke

The unburnt carbon particles are expelled out through the exhaust manifold as smoke which is shown in Figure 4. Smoke emission increases with the increase in brake

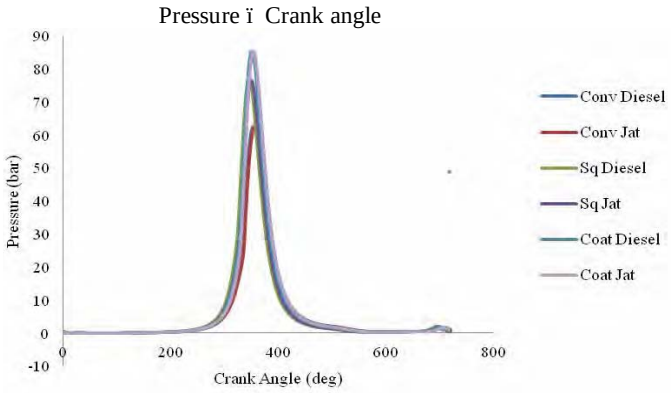

Fig. 5ð Pressure ï Crank angle

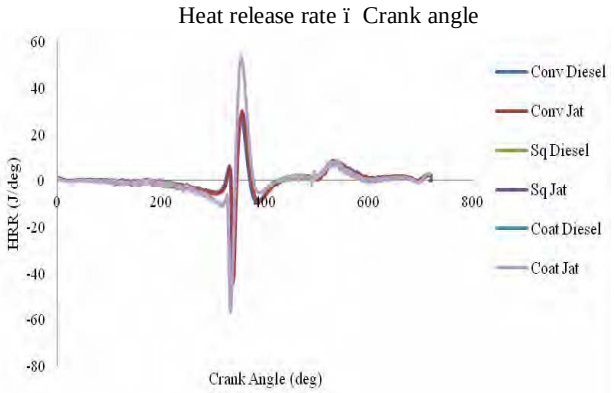

Fig. 6ð Heat release rate ï Crank angle

power. Smoke emission for the Jatropha fuel was lower than that of diesel fuel. This may be due to better atomization and vaporization of fuel causes complete combustion and reduced smoke emission. Smoke emission was lesser for the squish piston about 34.54% and for coated squish piston were 40.13% when compared with conventional piston.

Combustion

Effect of pressure

The effect on pressure at various crank angles is plotted in graph and shown in Figure 5. Pressure being the most important combustion parameter attains its maximum level after showing that the maximum pressure occurs at the end compression stroke. At maximum load, the peak pressure for conventional piston and squish piston are 67.05% and 76.65% respectively when it fueled with Jatropha biodiesel. At full throttle condition, the maximum pressure for the squish piston fueled Jatropha biodiesel is increased by 12.52% compared to the conventional piston.

Effect of heat transfer rate

Heat release rate is the rate of heat released from the combustion chamber during combustion. Figure 6 shows the instantaneous heat release rate of conventional piston and squish piston fueled with Jatropha biodiesel and diesel fuel. Maximum heat is released at the end of the compression stroke, i.e., immediately after the combustion starts. Heat release rate for the squish piston is higher compared to that of conventional piston. This is due to the squish head provided in the piston bowl allowing the fuel to mix well with the air. Thus improved combustion is achieved and hence the peak cycle temperature is increased. Maximum heat transfer rate is at the peak cycle temperature

By providing the thermal barrier coating to the inner side of the combustion chamber, reduces the heat rejection to the coolant. This heat may effectively utilized by the fuel for better vaporization and combustion. The better combustion increases the peak cycle temperature; due to the high combustion temperature increases the rate of reaction. Thereby some of the unwanted gases like NOx might have increased. But in other way the increase in temperature helps to produce more power output and thermal efficiency.

Conclusion

Raw Jatropha oil was modified into Jatropha biodiesel by transesterification process, the most simplest and efficient method for biodiesel production. Due to its optimum viscosity, specific gravity and higher energy content, the brake thermal efficiency was increased for Jatropha biodiesel. The higher oxygen content helps in reducing the emissions like HC, CO, Smoke, etc. But CO_2, NO_X increases because of the increase in peak cycle temperature, i.e., due to improved combustion. The squish head helps in better turbulence resulting in better combustion with reduced emissions than that of conventional piston. The thermal barrier coating given on the top surface of the piston bowl along with the squish head helps in reducing the heat rejection to the coolant. Since the thermal barrier coating acts as insulation, the combustion chamber temperature retains within the combustion chamber. This helps increase the temperature inside the combustion chamber resulting in improved vaporization and combustion with reduced emissions compared to squish piston.

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