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Performance of Compression Ignition Engine with Coated Piston for Multiple Blends of Methyl Castor Oil

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ABSTRACT:

Fossil fuel is getting exhausted at a fast rate and contributes to high carbon monoxide emissions. Biodiesel, being environmentally friendly, has better performance than diesel. Castor oil is an easily available vegetable oil in India. But its high viscosity leads to blockage of the fuel lines. The amount of free fatty acid more than 1% leads to soap formation which necessitates the biodiesel production in a two step process. The first step of acid catalyzed esterification process reduces the free fatty acid content of castor oil to below 1%. The second step of transesterification process converts the preheated oil to castor biodiesel. This two step process gave a maximum yield of 90%.The methyl castor oil (biodiesel) is blended with diesel in different proportions on volume basis as 15:85 (B15), 25:75 (B25), and 35:65 (B35). These blended oils are used to run a single cylinder four stroke compression ignition engine with different coatings of pistons, to study and compare the engine performance and emission characteristics at different load conditions.

KEYWORDS:

Biodiesel; Internal combustion; Piston coating materials; Brake thermal efficiency; Specific fuel consumption

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1. Introduction

In today's scenario of vastly depleting fossil fuels, the necessity of an alternative fuel which is efficient, renewable and easily accessible has become inevitable. The major alternative fuels being used in automotive transport are ethanol, hydrogen and biodiesel. Ethanol as a fuel is successfully established and commercialized in both developing and developed countries. But ethanol use is limited only to spark ignition engines and also limited to maximum blend strengths of up to 20% only, because higher blends result in fuel injection system problems. Hydrogen-based fuel cells could become a possible alternative to fossil fuels as many technical challenges need to be addressed, and for example, complexity in hydrogen production, necessities of special infrastructure for its storage, and production costs. Biodiesel is one of the most suitable for renewable, alternative and environmentally friendly bio-fuels which could be used in diesel engines, with slight or no requirement of engine modifications.

Biodiesel helps to reduce the exhaust emission characteristics of an engine which is matter of great interest as air pollution primarily is caused by the combustion of fuel in automobile engines and even a little reduction in this exhaust emission will help to decrease the adverse effect of global warming. Biodiesel processed from castor oil plant is cultivated in India at huge amount, has a high potential to become an alternative fuel to replace diesel. The high viscosity and low volatility are the major limitations of vegetable oils for their utilization as fuel in diesel engines. Because high viscosity vegetable oils reduce the atomization, evaporation and air-fuel mixture formation leading to incomplete combustion and higher smoke emission. Moreover this higher viscosity generates operational problems like difficulty to start the engine, improper ignition and decreases in thermal efficiency. However, these effects can be reduced or eliminated through transesterification process for separation of glycerol from the triglycerides.

The second aspect of our study deals with an effort to increase efficiency of the engine. It is well known fact that more than half of the energy produced in the combustion chamber of an internal combustion chamber is lost from the system through frictional losses, exhaust and cooling. The heat is transferred from various engine parts like the valves, piston surfaces and rings. If this heat loss is however reduced to some extent, the thermal efficiency of the engine can be significantly increased. In this experimental study the suggested idea to reduce the heat losses is to coat the piston crown with a thermal barrier coating. Thermal barrier coatings are usually multilayer ceramic coatings, over metallic surfaces, subjected extreme thermal and chemical environments. These materials have lower weight and low thermal conductivity. Coating is to provide thermal insulation at high temperatures. Coating material and its thickness are major variables to be concerned while designing a thermal barrier coating. Both of these significantly affect the engine performance and emission characteristics. In this study, Yttrium Stabilized Zirconium (YSZ) is used as a thermal barrier coating for the piston crown.

2. Biodiesel preparation

Biodiesel is composed of long-chain fatty acid with an alcohol attached, derived from vegetable oils. It is produced through the reaction of a vegetable oil with methyl or ethyl alcohol in the presence of catalyst. Animal fats are another potential source. Commonly used catalyst is sodium hydroxide (NaOH) or potassium hydroxide (KOH). The chemical process is called transesterification which produces biodiesel and glycerine. Chemically, biodiesel is called as a methyl ester if the alcohol used is methanol. If ethanol is used, it is called an ethyl ester. Both are similar, but methyl ester is cheaper due to lower cost for methanol. Biodiesel can be used in the pure form, or blended in any amount with diesel fuel for use in compression ignition engines. For safety, safety spectacles and gloves are worn during the process of making and testing the biodiesel. 500 ml of castor oil and 2 ml of concentrated H_2SO_4 poured in a round bottom flask and it is heated up to 80°C separately as shown in Fig. 1. 125ml of methanol was added with 3g of sodium hydroxide (NaOH) pellets and is mixed together until NaOH pellets dissolve in methanol. The above mixture is called as methoxide solution. The heated castor oil and concentrated H_2SO_4 solution is normally cooled upto 60°C and it is mixed with methoxide solution in conical flask. The conical flask was closed with a cork and was mixed until heated oil and methoxide solution are mixed together. The above mixture is poured into the separator funnel and it was allowed to set for 24 hours, when the ester and glycerine were separated. The upper layer of the separator funnel is ester and the lower layer of separator funnel is called glycerine.

Fig. 1: Experimental setup (Left) and Heating process (Right)

The separation of biodiesel from its by-products is done by washing of methyl ester with distilled water as shown in Fig. 2. This process is continued until the glycerine is removed. Filtered biodiesel was stored in a separate container. After the transesterification reaction, glycerol settles at the bottom of the container. This happens because glycerol is heavier then biodiesel. This mixture should be left a minimum of 8 hrs (preferably 12hrs) to make sure all of the glycerol has settled out. The glycerol volume should be approximately 20% of the original oil volume. During esterification process, when the temperature reaches above 60°C methanol evaporated. The evaporated methanol can be recovered with the help of condenser and can be reused for esterification process. Methanol recovery is important to reduce the manufacturing cost of biodiesel. Different ratios of diesel and biodiesel are mixed together and different blends are prepared.

Fig. 2: Washing process

3. Experimental setup & procedure

The specifications of the diesel engine used in the performance analysis are given in Table 1. The piston of the engine is coated with YSZ of 150μm, 250μm and 350μm thickness. The un-coated and coated pistons are shown in Fig. 3 and Fig. 4 respectively. Piezoelectric transducers are used to measure the pressure. A crank angle encoder is used to found the top dead centre position and the phasing of cylinder pressure to crank angle. PC based combustion analysis hardware and software are available to analyse the pressure data. The hardware is capable of applying loads at 50%, 75% and 100% of maximum load. Emission test was conducted using the exhausted gas analyzer coupled to the test engine. In this test the output result from exhaust gas analyzer was noted for each set of loads. The performance tests were conducted in constant speed air cooled 4 HP Greaves engine. The test has been conducted for diesel and various blends (such as B15, B25, B35 and B100) at various loads. A photograph of the test setup is shown in Fig. 5. The engine was coupled to mechanical loading through a transmission shaft. The maximum load which engine could take is at 1500 rpm. Study was carried out to investigate the effect of change of injection pressures on emission properties of methyl ester castor fuel in a stationary single cylinder diesel engine and to compare it with diesel fuel. The engine was coupled to Eddy current dynamometer. AVL-DIGAS 444 (five gas analyzer) was used for the measurement of carbon monoxide (CO) and hydro-carbon (HC) emissions. The specifications of gas analyser are given in Table 2.

Table 1: Specifications of Kirloskar single cylinder diesel engine

Particulars	Details
Power	4.4 kW
Speed	1500 rpm
Bore	87.mm
Stroke	110mm
Orifice diameter	13.6mm

Table 2: Specifications of AVL pressure transducer

Specification	Value
Sensitivity	18.99 pC/bar
Linearity	± 0.3%
Measurement range	250 bar
Temperature range	400 °C
Natural frequency	115 kHz

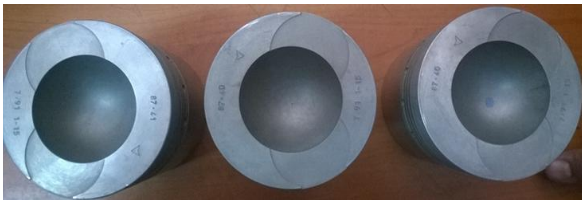

Fig. 3: Un-coated pistons (top view)

Fig. 4: Coated pistons (top view)

Fig. 5: Experimental setup

4. Results & discussions

The engine was operated first on diesel, then on methyl castor oil and blends were subjected to different piston coatings in engine and their emission characteristics were tested on the smoke analyser. The performance data were then analyzed from the graphs regarding brake thermal efficiency (BTE), specific fuel consumption (SFC), CO and HC emissions for different blends of fuel with different piston coatings. Theoretically if the heat rejected could be reduced, then the thermal efficiency would be improved, at least up to the limit set by the second law of thermodynamics. The results of the different blends of methyl ester castor oil to run the four stroke engine with different piston coatings values are given in Table 3 and the same are plotted in Fig. 6 to 9. When the all the three pistons are tested using conventional diesel, the piston 3 with coating thickness 350 microns has higher BTE. Piston 1 and piston 2 with coating thickness 150 and 250 microns respectively has moreover same BTE till 50% loading, and then a slight increase in the BTE of piston 2 is observed over piston 1. Similarly, the total fuel consumption for piston 3 is lesser than the other two pistons at all loads. When the exhaust emissions were compared in all pistons both CO and HC emissions are less when using piston 3. Comparisons of biodiesel blends B15, B25 and B35, the BTE is found to be higher in piston 3 with coating thickness 350microns. Exhaust emissions for biodiesel blends were compared in all pistons, the piston 3 (coating thickness 350microns) is found to give least CO for blends B15, B25, and B35 and B100. Therefore, the efficiency of the engine is found to be increasing as the coating thickness increases. The exhaust emissions are found to decrease till a coating thickness of 350 microns.

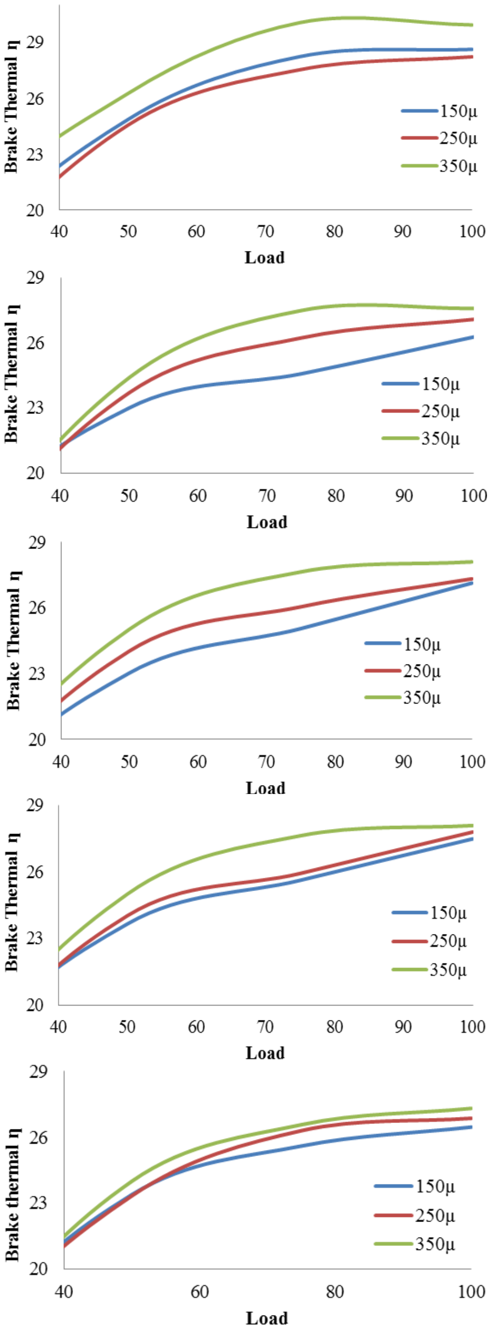

Fig. 6: Brake thermal efficiency vs. Load, Top to Bottom – Diesel, B15, B25, B35, B100

Table 3: Performance and emission results for multiple blends of Methyl Castor Oil fuelled engine with different piston coatings

Piston1	Load	BTE			SFC			CO			HC		
		150µm	250 µm	350 µm	150 µm	250 µm	350 µm	150 µm	250 µm	350 µm	150 µm	250 µm	350 µm
Diesel	50	24.88	24.58	26.27	0.343	0.336	0.315	0.02	0.02	0.02	20	19	18
	75	28.24	27.53	30.06	0.293	0.303	0.273	0.02	0.015	0.01	21	20	20
	100	28.62	28.23	29.93	0.289	0.291	0.277	0.05	0.035	0.04	29	28	24
B15	50	23.02	23.72	24.42	0.364	0.353	0.343	0.02	0.025	0.02	24	22	20
	75	24.58	26.23	27.49	0.317	0.329	0.305	0.02	0.023	0.015	24	21.5	21
	100	26.27	27.08	27.58	0.319	0.323	0.304	0.05	0.04	0.035	30	30	24
B25	50	23.02	24.03	24.71	0.353	0.353	0.343	0.02	0.02	0.02	21	22	20
	75	25.05	26.04	26.04	0.303	0.325	0.282	0.022	0.023	0.02	22	23	21
	100	27.13	27.33	28.43	0.313	0.298	0.298	0.045	0.04	0.038	26	25	22
B35	50	23.67	24.04	25.02	0.361	0.350	0.341	0.025	0.02	0.014	24	21	20
	75	25.63	25.94	27.64	0.309	0.320	0.292	0.02	0.02	0.016	24	22	21
	100	27.5	27.81	28.1	0.305	0.304	0.305	0.043	0.04	0.029	27	25	23
B100	50	23.4	23.35	24.01	0.386	0.390	0.380	0.02	0.018	0.01	15	13	11
	75	25.61	26.31	26.58	0.352	0.360	0.337	0.02	0.017	0.01	14	13	12
	100	26.47	26.87	27.32	0.326	0.345	0.330	0.03	0.027	0.02	19	16	13

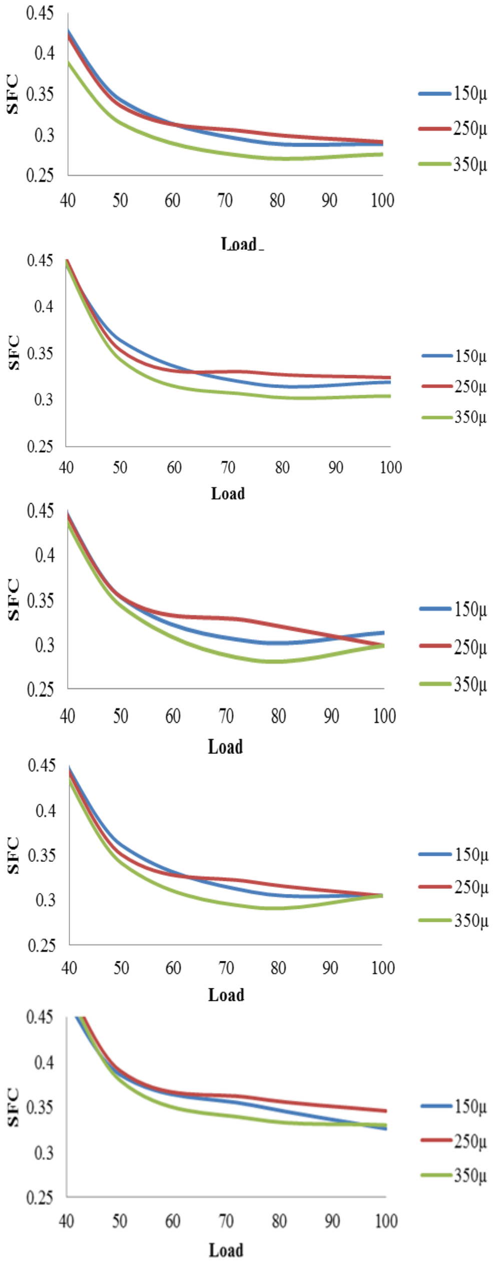

Fig. 7: Specific fuel consumption vs. Load, Top to Bottom – Diesel, B15, B25, B35, B100

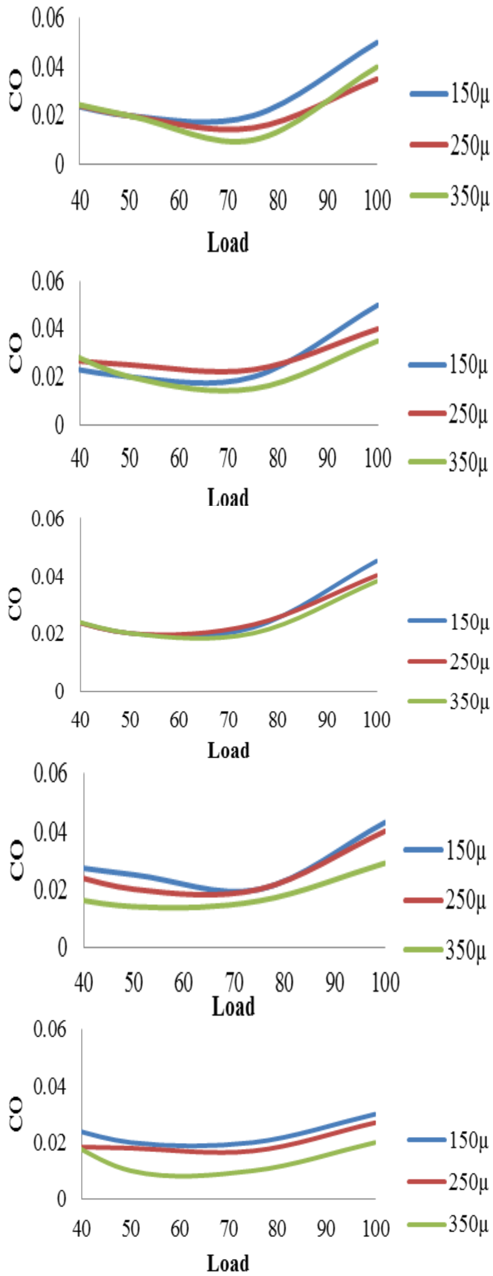

Fig. 8: Carbon monoxide emission vs. Load, Top to Bottom – Diesel, B15, B25, B35, B100

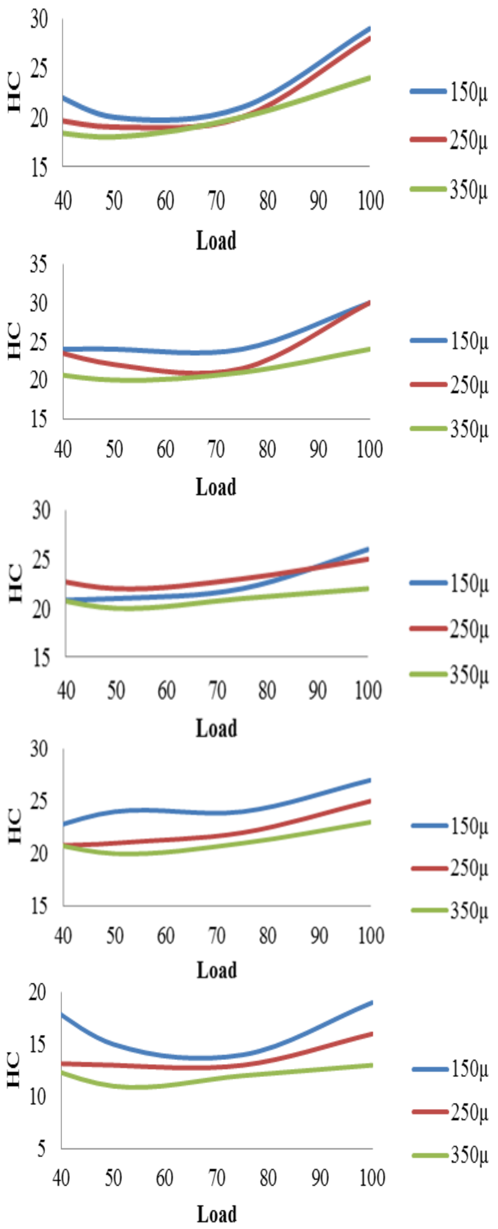

Fig. 9: Hydrocarbon emission vs. Load, Top to Bottom – Diesel, B15, B25, B35, B100

5. Conclusion

The performance and emission tests were conducted to study the effect of thermal barrier coating thickness on the piston crown of a diesel engine using methyl castor oil. The thermal efficiency of the diesel engines is observed to increase with increase of thermal barrier coating thickness. In this study piston 3 with coating thickness of 350 microns is found to give the best efficiency with least total fuel consumption, HC and CO emissions. Castor biodiesel is observed to give promising results to be used as an alternate fuel. The power produced by biodiesel (B100) was comparatively lesser than that generated by diesel fuel. Hence, thermal barrier coating is found to be an effective methodology to improve the thermal efficiency of diesel engine.

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