Performance and Emission Analysis of Partially Insulated Four Stroke Diesel Engine Fuelled with Blends of Sunflower Methyl Ester

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Abstract— *Methyl esters extracted from vegetable oils are an important alternative fuel for diesel. The direct usage of these fuels without any modification damages engine parts. The performance of these fuels in a diesel engine can be improved by providing insulation to the inner walls of combustion chamber. It increases the operating temperature within the combustion chamber reducing the viscosity of methyl esters which have higher viscosity than diesel. These low quality fuels can be more readily used in Low Heat Rejection engines.*

In this experimental study, cylinder head, inlet and exhaust valves and piston were coated with Yttrium stabilized Zirconia using plasma spray technique. The effects of Sunflower methyl ester from Transesterification method blended in diesel as a fuel in diesel was studied in both performance and emission aspects. An increase in engine brake thermal efficiency and decrease in specific fuel consumption was observed for pure diesel and the characteristics of methyl ester were better in case of coated engine rather than uncoated engine. Significant reduction in emissions were observed for methyl esters except CO at full load and NO_x *at all load conditions in case of coated engine compared to uncoated engine.*

Keywords — *Diesel engine, coating, Sunflower, Yttrium Stabilised Zirconia, YSZ, emissions.*

I. Introduction

In recent times, research is mainly focused on decreasing the costs and fuel consumption of internal combustion engines. Fuel energy must be converted to mechanical energy at the most possible rate to increase the engine performance. A look on the heat balance on conventional IC engine indicates that only one-third of fuel energy is converted to useful work, one- third lost to coolant and the remaining was lost through exhaust [1]. The improvement in engine efficiency through constructional features has increased. Ceramic coatings when applied to combustion chamber walls increase the combustion temperature and pressure inside the cylinder by reducing the heat loss. It was reported that higher temperatures in combustion chamber reduces the self-ignition delay [2-3]. Theoretically, higher the decrease in heat transfer rate in diesel cycle, lesser the energy loss [4]. Thermal barrier coated engines can be considered as a step to adiabatic engines. Diesel engines whose combustion chamber inner walls are insulated are referred to as Low Heat Rejection (LHR) engines [5].

Vegetable oil based biodiesel fuels in blends with diesel produce less smoke, low HC and CO and have higher cetane number [6-8]. Usage of high viscosity vegetable oils without any modification negatively affects the performance of diesel engine as the contaminant sticks to piston rings [9]. One of the significant method of making the vegetable oil to be used in engines is Transesterification method [10].Several studies had shown significant reduction in emissions while using blends as fuel.

Methyl esters produced from vegetable oils can be directly used in diesel engines as fuel with little or no modification. Though the characteristics of Methyl ester have been made similar to diesel by trans-esterification, its viscosity remains higher than that of diesel. By insulating the combustion chamber inner walls, the in-cylinder operating temperature increases so that methyl esters can be used more readily and efficiently in coated engines than in uncoated ones.

II. Test Fuels

In the present work, sunflower oil methyl ester was selected as research fuel. Raw sunflower oil was esterified by Transesterification method. The blending of vegetable oil esters with diesel is the most common form of biodiesel. Sunflower oil Methyl Ester was blended with petroleum based diesel fuel (D) by volumes of 15% sunflower methyl ester to 85% diesel fuel (SFO 15), 30% sunflower methyl ester to 70% diesel fuel (SFO 30) and 45% sunflower methyl ester to 55% diesel fuel (SFO 45). The physical and chemical properties of test fuels were presented in Table 1.The usability of sunflower methyl ester in a thermally insulated diesel engine coated with Yttrium Stabilized Zirconia (YSZ) was investigated. Comparisons were made between sunflower methyl ester blends and diesel fuel between coated and uncoated engines.

III. EXPERIMENTAL SETUP AND TEST PROCEDURE

Experiments were carried out on a four stroke, single cylinder, water cooled DI diesel engine. The specifications of the test engine setup are presented in Table 2.

Rope brake dynamometer was used for performance tests of the engine. Schematic diagram of the engine setup is presented in Fig. 1.

TABLE 1

PROPERTIES OF THE TEST FUELS

Fuel type	Calorific value (kJ/kg)	Density (30^0C)	Flash point (^0C)	Fire point (^0C)
Diesel	45347	833	48	51
Sun Flower Methyl Ester	37680	892	157	161
SFME 15	44230	841	62	66
SFME 30	43050	852	79	81
SFME 45	41957	859	93	95

TABLE 2

TECHNICAL SPECIFICATIONS OF THE TEST ENGINE SETUP

TEST ENGINE	
Type of engine	High speed diesel engine
Make	Kirloskar AV 1
Injection system	Direct injection
No. of cylinders	1
Cylinder bore x stroke (mm)	80 x 110
Compression ratio	16.5 : 1
Injection pressure	200 bar
Maximum power	5 HP
Cooling system	Water cooled
ROPE BRAKE DYNAMOMETER	
Load type	Mechanical
Brakedrum diameter	0.315 m

The test engine was dismantled to find out the type of cylinder head, valves and piston. The mentioned parts with same technical specifications were bought which were than coated with Zirconia by plasma spraying technique. The Thermal Barrier Coating (TBC) applied to the engine parts consists of bond coat of NiCr 80 20 as oxidation resistant layer and top coat of YSZ that provides thermal insulation towards metallic substrate. The thickness of applied coating was 400µm along with bond coat. The required parts were grinded before applying the coating to maintain the same compression ratio. The surfaces to be coated and after coating are shown in Fig. 2 and 3 respectively.

The test engine is controlled to maintain a constant speed of 1500rpm. Load is varied and readings are taken at 0, 4, 8, 12

Fig. 1 Schematic diagram of the test engine setup

Fig. 2 Surfaces of engine parts to be coated

Fig. 3 Surfaces of engine parts after coating

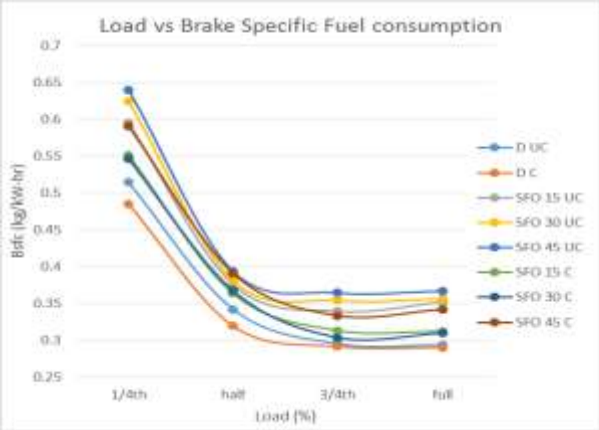

Fig. 4 Variation of Bsfc in relation with load

and 16kg which are considered as 0, 1/4th, ½, 3/4th and full load respectively.

IV. RESULTS AND DISCUSSION

The results of the engine tests are presented in Fig. 4-10 for each of the conditions. The conditions are represented as uncoated (UC) and (C) engine operation. All comparisons were made with respect to uncoated diesel fuel operation of the standard engine.

4.1 Performance

The variation of Brake specific fuel consumption (Bsfc) in relation to various fuels is shown in Fig. 4.

The Bsfc values for entire test fuels were decreased until 3/4th load and increased again, which might be caused due to difference in heating value, high density and viscosity of biodiesel. The average Bsfc decrease was 4.14% for coated diesel compared to uncoated diesel operation. Fuel consumption for biodiesel is higher than diesel fuel due to its lower energy content which made the engine consume more fuel to produce the same amount of power. It can also be observed that specific fuel consumption for sunflower methyl esters is less in coated engine when compared to standard uncoated engine at all loads.

The decrease in Bsfc in coated engines is attributed to the rise in operating temperature and decrease in ignition delay of the combustion cycle.

The variation of Brake thermal efficiency for all the test fuels against various loading conditions can be seen in Fig. 5.

An average increase of 4.48% was observed in brake thermal efficiency for coated diesel compared to uncoated engine. The highest Brake thermal efficiency resulted for diesel in coated engine at 3/4th of the maximum load.

The results show that engine operation with biodiesel can be improved by coating the engine. It can be attributed to the reduced heat transfer from the walls of combustion chamber. Because, when loss through heat transfer is reduced, the in-cylinder combustion temperature achieves a higher value.

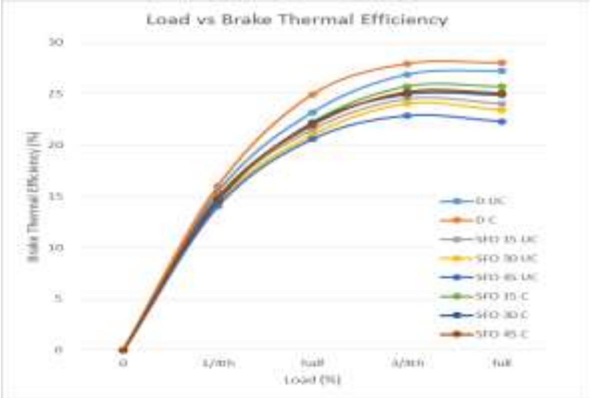

Fig. 5 Variation of Brake Thermal Efficiency in relation with load

Hence, high combustion temperature results in high in-cylinder pressure resulting high efficiency.

When load on the engine was increased the efficiency values also increased for all the engine test fuels. However after 3/4th load, the values decreased which can be due to mechanical losses and the inability of the engine to ingest a full charge of air at higher loads.

4.1 Exhaust Temperature and Emissions

Exhaust gas temperature variation of the test fuels at different loads is presented in Fig. 6. This temperature gives us an estimate of in-cylinder combustion temperature. From the figure, we can observe that exhaust temperature is high in case of coated engine operation for all test fuels compared to uncoated engine operation at all loading conditions. This can be attributed to decrease in heat loss due to insulation provided by the coating of combustion chamber walls.

From Fig. 7, we observe HC values decreased for coated engine operation. It can be seen that HC emissions were considerably decreased when using biodiesel blends. The higher oxygen content in biodiesel takes part in combustion and makes combustion environment enriched with oxygen, helping to achieve less in-complete combustion products such as HC and CO emissions.

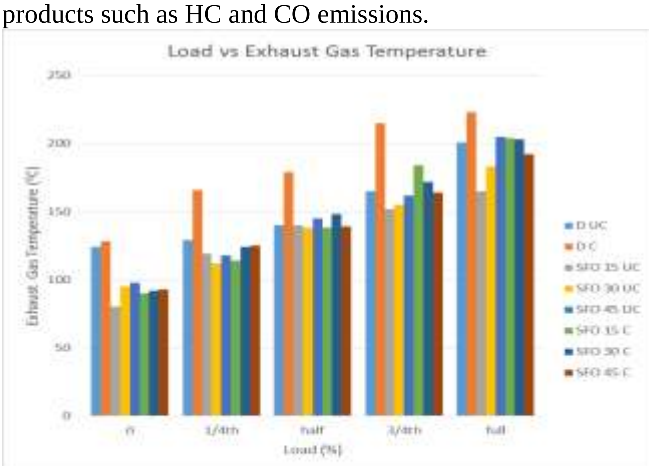

Fig. 6 Variation of Exhaust gas temperature in relation with load

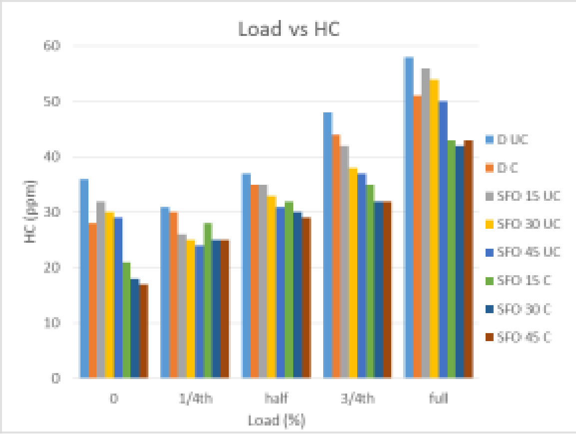

Fig. 7 Emission of HC at different load conditions

When both coated and uncoated diesel engine experiments were compared, average HC emissions were found slightly lower (nearly 10.47%) for coated diesel engine operation.

Lowest amount of HC emissions were recorded by SFO 45 C i.e., 30.4% and 22.3% lower than diesel operation in uncoated and coated respectively.

The most important factor of global warming problem of the world is the increase of CO2 emission which lead to greenhouse effect. CO2 is an emission product related to the entire combustion of the fuels. High post-combustion temperature and existence of enough oxygen for a more complete combustion increases the amount of CO2 in the exhaust gases.

Fig. 8 presents CO_2 emissions for all test fuels at different loads. The increase in CO_2 production with increase in blending percentage may be due to more efficient combustion. In presence of sufficient oxygen, more CO and HC can be converted into CO_2. Biodiesels had high oxygen content which leads to more complete combustion, therefore CO and HC emissions reduce, thus CO_2 emissions increase in the exhaust.

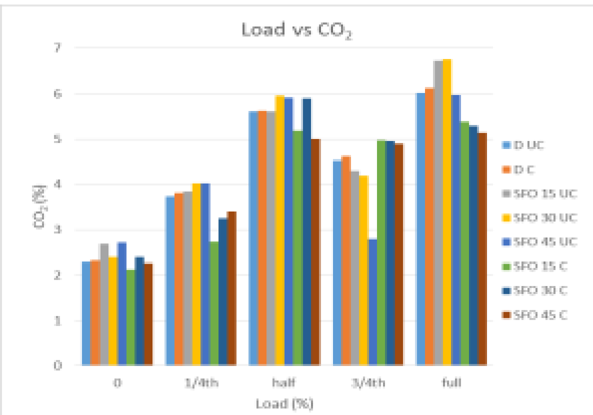

Fig. 8 CO_2 emissions at different load conditions

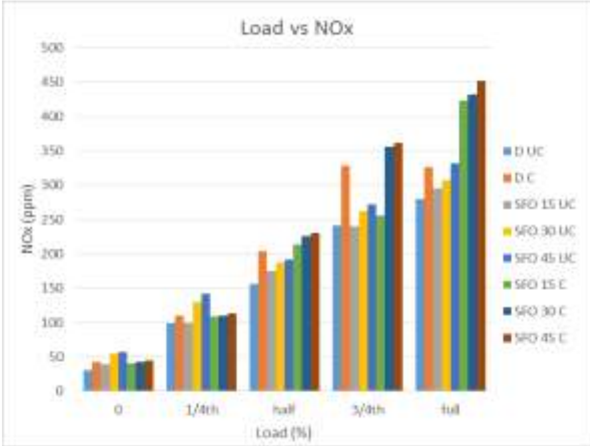

Fig. 9 NO_X emissions at different load conditions

Whereas they gradually increase with increase in load to catch up with diesel and decrease at peak load in coated engine operation.

NOx emissions are mainly produced at considerably high temperature combustion. From Fig. 9 lowest amount of NOx was obtained for Diesel uncoated operation. When engine is insulated, the combustion temperature increases and results in increased NOx emissions.

CO is the most toxic substance found in exhaust gases which is colourless, tasteless and odourless. CO emission is due to incomplete combustion.

CO emissions shown in Fig. 10 were considerably decreased for biodiesel usage in diesel engine. It is significant result of using vegetable based oils in diesel engines as fuel as they had high oxygen content. When coated and uncoated diesel engine emissions were compared, average CO emissions were found slightly lower for coated diesel engine operation.
CO emissions were lowest for D C operation and they decreased by 25.86% with respect to D UC operation.

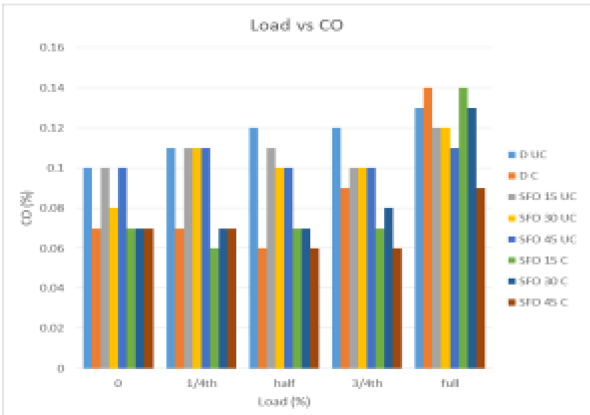

Fig. 10 CO emissions at different load conditions

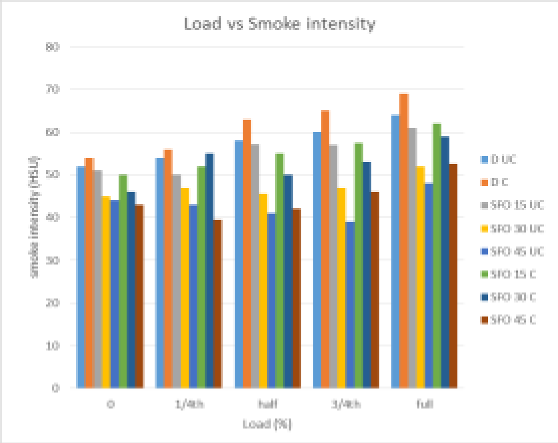

Fig. 11 Smoke intensity at different load conditions

Smoke opacity levels for different loads is presented in Fig. 11. Smoke levels obtained in the exhaust were decreased with increase of load for all test fuels. The highest smoke opacity levels were ever obtained for diesel fuel in coated engine. The lowest smoke emissions were obtained for SFO45 fuel in all engine operation conditions. Among blends the highest smoke opacity levels were obtained for SFO15 fuel. The main reason could be higher viscosity of the fuel and bigger size fuel molecules contained in the fuel resulting in poor atomization.

V. Conclusions

Thermal Barrier coatings are applied to inner walls of diesel engine in order to increase thermal efficiency and improve combustion. In this experimental study, parts of the engine namely engine head, piston, inlet and exhaust valve surfaces which are exposed to combustion flame were coated with Yttrium stabilized Zirconia giving the engine Low Heat Rejection feature.

The following conclusions can be drawn from this experimental study:

1. The amount of Bsfc decreases for all test fuels for coated engine compared with uncoated engine. The average decrease is 4.14% and 5.66% when diesel and blends were used in coated engine compared with standard engine.
2. Brake thermal efficiency of coated engine increased due to reduction in Bsfc. It increased at an average of 4.48% in coated engine when fuelled with diesel. Also, blends have shown increase in efficiency in coated engine compared to standard engine.
3. The exhaust gas temperature increased for all test fuels in case of coated engine.
4. Hydrocarbon emissions were decreased while using blends in both the engines compared to diesel as fuel.
5. There was a slight increase in the amount of CO_2 released in case of coated engine showing improvement in combustion.
6. CO emissions were considerably decreased especially when blends of sunflower methyl ester were fuelled in diesel engine except at full load conditions where they increased rapidly which can be reduced using a turbocharger. Emissions were lowest during coated diesel operation and lowered by 25.86% compared to base fuel.
7. NO_x emissions found to increase in case of coated engine due to prevailing high temperatures during combustion due to the presence of insulation provided by coating.
8. Smoke intensity was significantly reduced with increase in proportion of blends for both coated and uncoated engines. Average decrease was determined to be 8.68% when blends of sunflower methyl ester was used as fuel.

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