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Performance and Emission Characteristics of a Low Heat Rejection Diesel Engine Operated on Sea Lemon Oil Biodiesel and Diesel Fuel Blends

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Abstract

The objective of this study was to observe the combined effects of biodiesel (Sea Lemon oil) and a low heat rejection combustion technique. For this purpose a single cylinder four stroke direct injection diesel engine was converted into a low heat rejection engine, and its performance and emission characteristics were investigated experimentally. The experiment has been carried out on two phases. In the first phase, the blends of Sea Lemon oil and diesel fuel were injected at various loads in a conventional single cylinder four stroke direct injection diesel engine. In the second phase,conventionaldiesel engine's cylinder head, valves, and pistons were coated with 0.15 mm of nickel-chrome-aluminum bond coat and 0.35 mm of yttria-stabilized zirconia (YSZ). Thus, a thermal barrier was produced for the elements of thecombustion chamber. The main purpose of engine coating was to reduce heat rejection from the walls of combustion chamber and to increase thermal efficiency and thus to increase performance of the engine that using vegetable oil blends. From the results, it is observed that there will be a significant decrease in specificfuel consumption and an increase in brake thermal efficiency. Also, there is a significant reduction incarbon monoxide, oxides of nitrogen except unburned hydrocarbon emission, and smoke density forall test fuels used in the coated engine as compared to the uncoated engine.

Key words: Sea Lemon oil; yttria-stabilized zirconia; thermal barrier coating.

1. Introduction

In recent times, the world is confronted with the twin crisis of fossil fuel depletion and environmental degradations. The situations have led to the search for an alternative fuel which should be not only sustainable but also environment friendly without sacrificing the performance. Thedifferent sources for alternative fuels are edible and non-edible vegetable oils, animal fats and waste oil (triglycerides). Vegetable oils, being renewable, are widely available from variety of sources have low sulfur contents close to zero and hence cause less environmental damage (lower greenhouse effect) than diesel. In the context of India, non-edible vegetable oil can be the most viable alternative for petroleum fuels since there is shortage of edible oils to meet the domestic requirements.

It has been reported that used cooking oil biodiesels are usually the same as biodiesel from fresh vegetable oil. So the influence of used cooking oil biodiesel (like biodiesel from neat vegetable oil) on engine performance and combustion characteristics is probably more closely related to the oxygenated nature of biodiesel (which is almost constant for every biodiesel), and also to its higher viscosity and lower calorific value, which have a major bearing on spray formation and initial combustion [1]. Also, it is reported that, utilization of waste cooking oil is a key component in reducing biodiesel production costs up to 60-90% [2]. Thermal barrier coatings (TBCs) are applied to diesel engines in order to improve the performance of the engine and reduction of pollutant emissions [3]. TBCs are also applied in adiabatic engines for possible reduction of engine emissions [4]. Thermal barrier coatings are used to improve reliability and durability of hot section metal components and enhance engine performance and efficiency in internal combustion engines. It is reported that constructional problems evolved concerning the compatibility of the new ceramic materials used as insulation along with the conventional ones [4]. Different composites like SiCa, silicon nitride, Al, MgSiO2 and other ceramic materials were used in low hear rejection engine concept [5].

2. Materials and Methods:

2.1 Biodiesel Production Process

Ximeniaamericana, commonly known as yellow plum or sea lemon, is a small sprawling tree of woodlands native to the tropics.Leaves are oval shaped, bright green and have a strong smell of almonds. Flowers are pale in color. Fruits are lemon-yellow or orange-red.

Sea lemon oil was used to produce the biodiesel.

1. Alcohol and catalyst mixture:
   Potassium hydroxide (KOH) was used as a catalyst in the transesterification process. Methanol was chosen in biodiesel production due to its low cost and physical and chemical advantages. Thirty-five grams of potassium hydroxide (KOH) and 2 liters of methyl alcohol (CH3OH) were used for esterification of 10 liters of Sea lemon oil.
2. Transesterification:
   The Sea lemon oil, alcohol, and catalyst mixture was poured into a reaction tank. Temperature and mixing speed of the mixture were kept constant during the esterification.
3. Separation:
   When the transesterification was completed, the mixture was taken to a tank to settle. After settlement of the methyl ester and glycerin, the glycerin was drained.
4. Washing process of methyl ester:
   The methyl ester was washed for 12 h with pure water to remove alcohol and catalyst residue. After the separation of the methyl ester and water following the washing process, the water was then drained.
5. Drying process of methyl ester:
   To eliminate the water in the methyl ester that remains from washing, it was dried by heating up to 100ıC for half an hour. The water in the methyl ester was evaporated during the drying process.

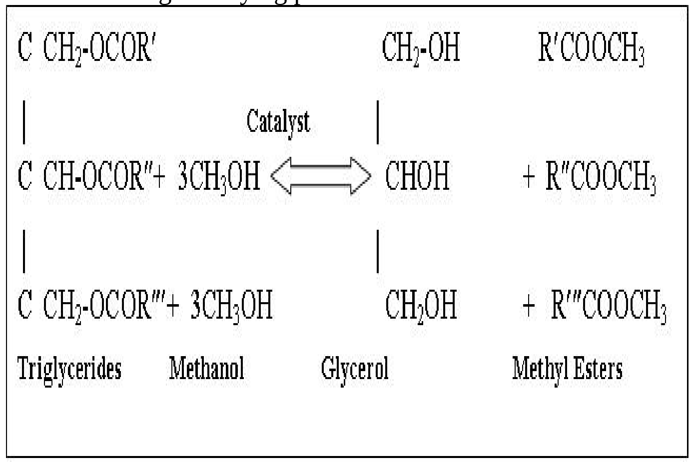

Figure 1 Transesterification chemical reaction.

2.2 Plasma Coating Process

The cylinder head, valves, and pistons of the test engine were coated with an atmosphericplasma spray coating method. Before coating, a 0.5 mm thickness of material wasremoved from surfaces by machining to keep the compression ratio of the LHR enginethe same as the standard engine. The combustion chamber components were coated with a Y2O3-ZrO2 (yttria-stabilized zirconia) layer of 0.35 mm thickness over a NiCrAl bond coat of 0.15 mm thickness.
The yttria-stabilized zirconia was chosen as ceramic material because of its durability in a high temperature environment. The coating was applied with the atmospheric plasma spray method. This method was both economical and easy to accomplish. The coated parts of the engine can be seen in Figure 2. Thus, the test engine was converted to LHR condition. The same test procedure was conducted for the LHR engine and the results were compared.

3. ENGINE TEST

The engine operated for 30 min with diesel fuel to attain a normal working temperature. In the first phase, the test was conducted in the uncoated engine (UCE) and the results were obtained. In the second phase of work, the tests were repeated under the same conditions in the coated engine (CE). The engine was maintained at a constant speed and all of the measurements were repeated at least three times.

Finally, the average value of three readings was taken for the calculation.

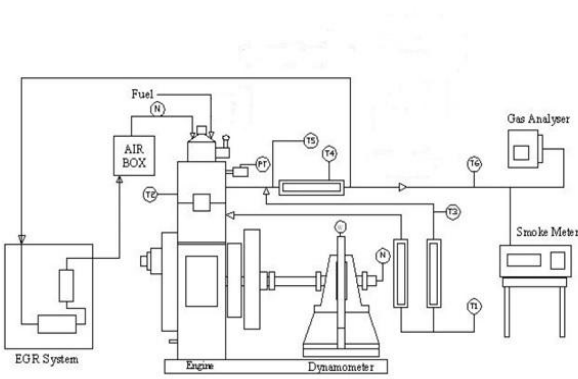

Fig.2 Experimental setup

Fig.3 Coated (YSZ material) cylinder head and piston

Table 1 properties of sea lemon oil biodiesel

Property	Diesel	Sea lemon oil
Kinematic viscosity in cst at 40^0 C	3.1	4.9
Calorific value in Kj/kg	43200	39800
Density at 15^0C in kg/mm^3	830	860
Cetane no.	46.4	50
Flash point (^{0}C)	56	75
Fire point (^{0}C)	64	92

4. Results and Discussion

4.1 Brake Specific Fuel Consumption

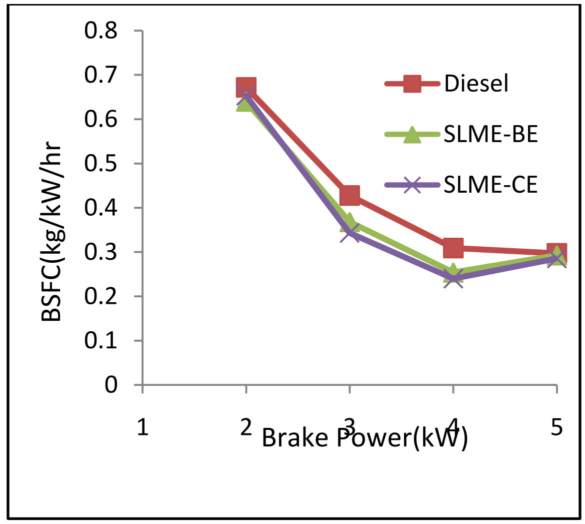

Figure 4. Brake Power Vs BSFC

Figure 4 shows variation of brake specific fuel consumption with respect to blend ratio for coated and conventional engines at full load for neat biodiesel to neat diesel. From the graph, it can be seen that there is an increasing trend observed with respect to blends of fuel. The coated engine with neat diesel gives better brake specific fuel consumption as compared to the conventional diesel engine at full load. The effect of increased in-cylinder temperature due to the thermal barrier coating and the consequence in the decreased specific fuel consumption.

4.2 Brake thermal efficiency

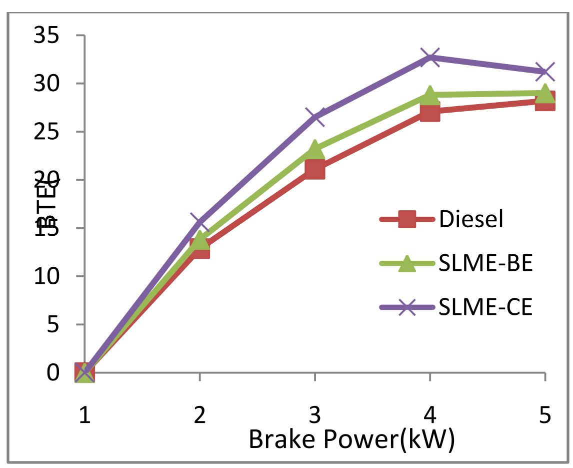

Figure 5. Brake Power Vs BTE

The effect of brake power on brake thermal efficiency (BTE) for diesel, sea lemon oil in the normal engine operation is shown in Figure 5. It can be observed that there was a steady increase in BTE as the load increased for the diesel, sea lemon operations. The BTE was found to be lowest for the biodiesel operations compared with the diesel operation. This reduction may be due to their lower volatility, higher viscosity and density, leading to poor mixture formation.

4.3 CO emissions

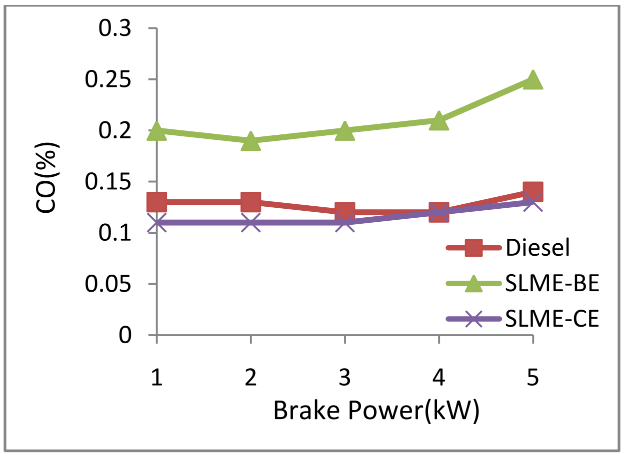

Figure 6. Brake Power Vs CO

CO emissions were considerably decreased for vegetable oil usage in diesel engine. It is one of the most important and beneficial results of using sea lemon oil in diesel engines as fuel. This crucial result is achieved thanks to the oxygen amount inherently contained in the sea lemon chemical construction. When the engine coating is taken into consideration both two diesel fuel experiments should be analyzed can be seen in Figure 6. When both coated and uncoated diesel engine experiments were compared with each other, average CO emissions were found slightly lower for coated diesel engine operation even though the main purpose of insulation of the engine was to improve the performance and usability of sea lemon in diesel engines.

4.4 HC emission

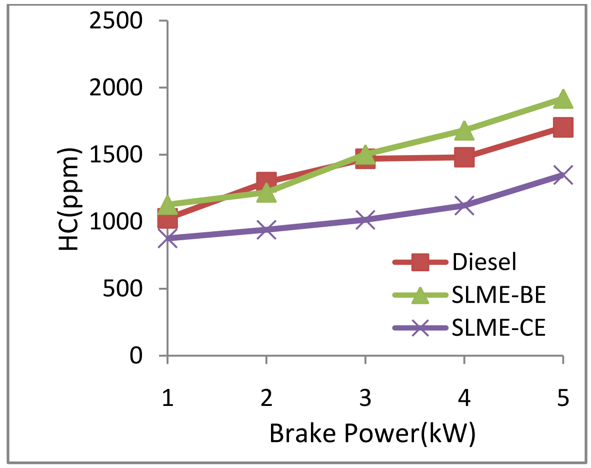

Figure 7. Brake Power Vs HC

This surplus benefit can also be seen in HC emission values as they were also decreased for coated engine operation. HC emissions results, for all test fuels, can be seen in Figure 7. It can clearly be observed from that HC emissions were considerably decreased when using vegetable oil blends fuel in diesel engine. The higher oxygen contented in the sea lemon diesel blend fuels take part in combustion and make the combustion environment enriched with oxygen. Hence, the surplus oxygen content helps to achieve more complete combustion thus results in decreased in-complete combustion products such as HC and CO emissions. When both coated and uncoated diesel engine experiments were compared, average HC emissions were found slightly lower for coated diesel engine operation.

4.5 NOx emission

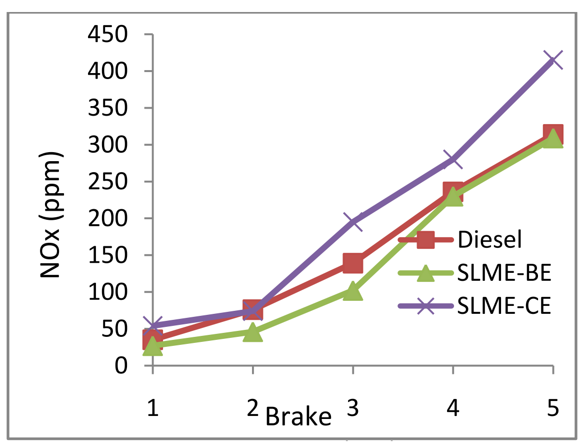

Figure 8. Brake Power Vs NOx

NOx emissions are mainly produced at considerably high temperature combustion. The prolongation of the high temperature regime results in NOx emissions accumulation. Thus total NOx emissions increase. As can be seen in Figure 8, the lowest NOx emissions were obtained for D2 usage in uncoated engine operation. When engine is insulated, the combustion temperature increases and results in increased NOx emissions. Therefore, Diesel usage in the coated engine operation resulted in considerably higher NOx emissions than normal Diesel operation. When all the test fuels were compared, sea lemon diesel blends resulted in more NOx emission than o diesel fuels operation. When sea lemon oil fuels are used in the test engine, the higher oxygen content is considered to improve combustion and results in higher combustion temperature and thus higher NOx emissions as well.

Conclusion

Specific fuel consumption of YSZ coated engine was lower at all loads, because of the insulation effect of coating and changes in combustion process due to coating. The BTE increases in the order of MEOSL - YSZ MEOSL - Diesel - YSZ Diesel. The maximum increase in BTE of about 32% is achieved for YSZ coated engine fueled with diesel at maximum load condition.

HC, CO and Smoke emission of the MEOSL was lowered due to the higher oxygen content of the fuel. YSZ coated engines emission was much lower than the convention engine for both the fuel. The NO_X emission is slightly higher for MEOSL due to oxygen content, YSZ coated engine also has higher NOx emission due to higher peak temperature inside the combustion chamber during combustion processes.

Experimental studies revealed that MEOSL can be used as a sole fuel in the YSZ coated diesel engine without any design modification to the existing engine.

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