APPLICATION OF THERMAL BARRIER COATING FOR IMPROVING THE SUITABILITY OF ANNONA BIODIESEL IN A DIESEL ENGINE

by

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The Annona biodiesel was produced from Annona oil through transesterification process. The aim of the present study is to analyze the performanceand emissioncharacteristics of a single cylinder, direct injection, compression ignition engine using a annona methyl ester as a fuel. They are blended together with the Neat diesel fuel such as 20%, 40%, 60%, 80%, and Neat biodiesel. The performance, emission and combustion characteristics are evaluated by operating the engine at different loads. The performance parameters such as brake thermal efficiency, brake specific fuel consumption. The emission constituents such as carbon monoxide, unburned hydrocarbons, oxides of nitrogen, and smoke were recorded. Then the piston and both exhaust and intake valves of the test engine were coated with 100 μm of NiCrAl as lining layer. Later the same parts were coated with 400 μm material of coating that was the mixture of 88% of ZrO_2*, 4% of MgO, and 8% of* Al_2O_3*. After the engine coating process, the same fuels is tested in the engine at the same engine operation. The same performance and emission parameters were evaluated. Finally, these parameters are compared with uncoated engine in order to find out the changes in the performance and emission parameters of the coated engine. It is concluded that the coating engine resulting in better performance, especially in considerably lower brake specific fuel consumption values. The engine emissions are lowered both through coating and annona methyl ester biodiesel expect the nitrogen oxides emission.*

Key words: *annona methyl ester, performance, exhaust emission, thermal barrier coating, Diesel engine*

Introduction

Even the Diesel engine rejects about two thirds of the heat energy of the fuel, one-third to the coolant, and one third to the exhaust, leaving only about one-third as useful power output. 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. Low heat rejection (LHR) engines aim to do this by reducing the heat lost to the coolant [1].

The Diesel engine with its combustion chamber parts insulated by ceramics is referred to as LHR engine. The LHR engine has been conceived basically to improve fuel economy by eliminating the conventional cooling system and converting part of the increased exhaust energy into shaft work using the turbocharged system. Thermal barrier coatings (TBC) in Diesel engines lead to advantages including higher power density, fuel efficiency, and multi fuel capacity due to higher combustion chamber temperature (900 °C *vs*. 650 °C) [2, 3]. Using TBC can increase engine power by 8% decrease the specific fuel consumption by 15-20% and increase

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the exhaust gas temperature by 200 °C [4]. Thin layer thermal barrier coated engine (CE) could improve performance when a high pressure injector unit was used and they underlined that a TBC offered higher efficiency by 5-6% compared to the standard engine. They also report significant improvement in fuel economy by insulating the diesel combustion chamber [5].

The LHR engine had lower thermal efficiency with higher smoke, particulates and CO emissions compared to that of standard cooled engine [6].

The TBC for Diesel engine is accepted to improve the engine thermal efficiency and reduced emissions as well as specific fuel consumption because of their ability to provide thermal insulation to the engine components. The generally known principle that increased operation temperatures in energy conversion systems lead to an increase in efficiency, fuel savings and reduced emissions as particles, CO, HC, and limited reductions of NO_x have, over many decades promoted R&D activities in the field of TBC development [7].

The Diesel engine generally offers better fuel economy than its counterpart petrol engine. Diesel engines operated on biodiesel have lower emissions of CO, unburned HC, particulate matter, and air toxics than that of diesel fuel [8].

The source for biodiesel production is chosen according to the availability in each region or country [9]. In this experimental work, *transesterification process* is used for producing biodiesel from the source vegetable oil. Biodiesel prepared from vegetable oil after transesterification reaction shows a similar performance to diesel at all loading conditions and can be used as alternate fuel to diesel without any modifications in engine design [10]. The direct use of vegetable oils for both direct and indirect injection type Diesel engines is unsatisfactory due to their high viscosities and low volatilities [11]. The diesel fuel cannot be replaced totally by the vegetable oils (in conventional Diesel engines) because of the low cetane number, high ignition temperature, high viscositym, and incomplete combustion leading to increased emissions and decreased performance [12]. Viscosity is the major problem for the bio-diesel which imposes lot of problems for engine [13]. Transesterification process removes fatty acids in the form of glycerol, thereby reduces the viscosity. Hence biodiesel can be used in compression ignition engines without any modification.

In this work, experiments were carried out on a single cylinder four stroke direct injection (DI) Diesel engine using annona methyl ester (AME) and its blends with diesel. They have reported that AME at 20% blend shows better performance and lower exhaust emission. They have also found that CO and HC, smoke emission reduced considerably and NO_x emission slightly increased for the various proportions of AME [14].

An LHR combustion chamber is one in which the heat rejected through the coolant is minimized by insulating the parts like cylinder liner, piston head, valves, and cylinder head using ceramic materials that possess the property of low thermal conductivity as well as low coefficient of linear expansion [15-20]. The LHR engines are classified according to their degree of insulation into (a) ceramic coated combustion chamber (low grade LHR engine), (b) air gap insulated combustion chamber (medium grade LHR engine), and (c) the combination of both (high grade LHR engine) [21, 22].

The present work is focused on the performanc and emission characteristics of AME by using different type's blends, to find its suitability as a fuel in a thermally insulated CE with the mixture of 88% of ZrO_2, 4% of MgO, and 8% of Al_2O_3 were investigated. The results are compared with CE and uncoated diesel engines (BE). This type of comparative study hasn't reported in the literature review.

Materials and methods

Test fuel (custard apple)

Annona squamosa seeds were Sun dried for a week to the required dry weight and moisture content and then the hard nuts of the seeds were removed by physically hitting with a hard metal and the kernel obtained. The seeds for this study were collected from ripened fruit, and grinded using home-blender without aprior drying process.

Experimental set-up and test procedure

The experiments were conducted on single cylinder, four stroke, water cooled DI Diesel engine using AME as a fuel.

The schematic diagram of the experimental set-up is shown in fig. 1. The rated speed of the engine is 5.9 kW and operated speed at 1800 rpm. The specifications of the engine were given in tab. 1. The piston and valves of the test engine were prepared for coating process. The thickness of coating layer on the piston and valves were 500 μm. Before coating was applied, the thickness of piston and valves reduced to 500 μm. Further, the piston and valves are coated with the 100 μm NiCrAl as lining layer. After that, same parts are coated with 400 μm coating material which is the mixture of 88% of ZrO_2, 4% of MgO, and 8% of Al_2O_3.

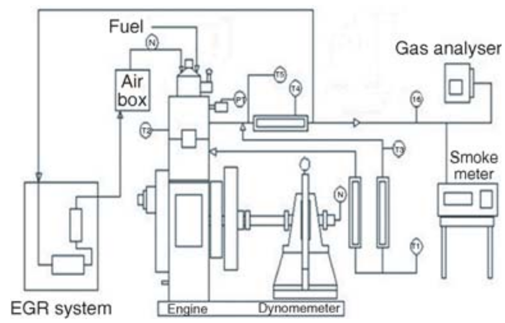

Figure 1. Experimental set-up

Table 1. Fuel properties

Properties	Diesel	A20
Cetane number	48	52
Specific gravity	0.83	0.8802
Viscosity at 40 °C	3.9	5.18
Calorific value [kJkg^{-1}]	43000	36400
Density [kgm^{-3}]	830	880.2
Flash point [°C]	56	76
Fire point [°C]	64	92

Results and discussion

Engine performance

Brake specific fuel consumption

The brake specific fuel consumption (BSFC) of various biodiesel blends and diesel for CE and BE is shown in fig. 2. It is observed that the coating engine operation result is minimum the BSFC for all AME blends. Among different biodiesels blends, A20 for CE showed minimum BSFC than that of BE diesel engine. The BSFC for A20 is CE is decreased by 11.73% when compared to that of BE and Neat diesel. This is due to increase in-cylinder gas and wall temperatures because of its coating material.

Brake thermal efficiency

The brake thermal efficiency (BTE) of various biodiesel blends and diesel for CE and BE engine is shown in fig. 3. Among different biodiesel blends, A20 for CE showed better BTE than BE and Neat diesel fuel. The BTE for A20 in CE is increased when compared to that of BE and Neat diesel fuel. The main reason for the increase in BTE is increase in cylinder temperature due to the coating material coated on the surface of the combustion chamber. It is believed that heat transferred through the combustion chamber was decreased due to coating process which results in increase the in-cylinder gas and wall temperature.

Emission characteristics

Carbon monoxide emission

The CO emission of various biodiesel blends and diesel for CE and BE is shown in fig. 4. Among all biodiesel blends, A20 for CE has lower CO emission than that of Neat diesel and

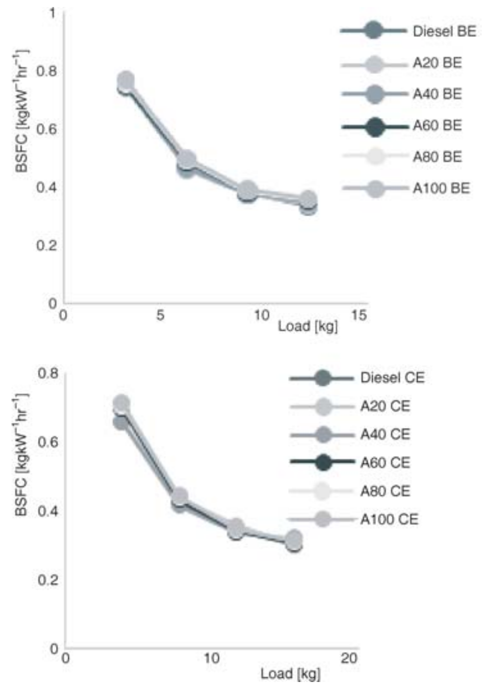

Figure 2. The Variations of load *vs*. BSFC for BE and CE

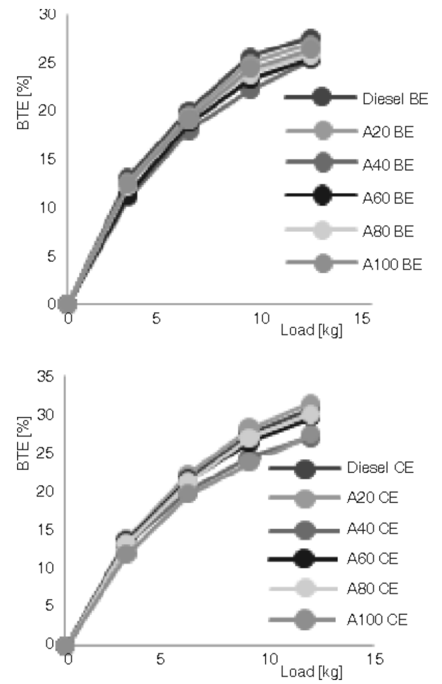

Figure 3. The variations of load *vs*. BTE for BE and CE

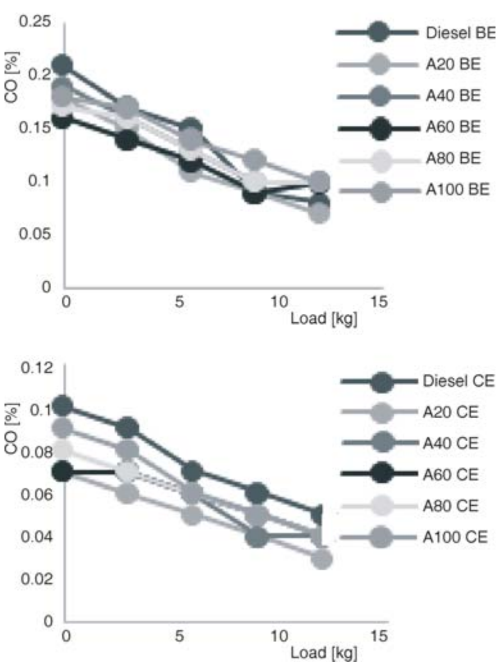

Figure 4. The variations of load *vs*. CO emission for BE and CE

BE at all loads. It is observed that, CO of A20 in CE is decreased by 35% when compared to that of BE and standard Neat diesel. The reason for reduction in CO emission is considered to be the higher combustion temperature which leads to higher temperature values in the late combustion phase that result in more CO oxidation.

Hydrocarbon emission

The HC emission of various biodiesel blends and diesel for CE and BE is shown in fig. 5. Among all biodiesel blends, A20 for CE has lower HC emission than that of Neat diesel and BE at all loads. It is observed that HC of A20 CE is decreased by 36.11% when compared to that of Neat diesel and BE.

Oxides of nitrogen emission

The variation of NO_x of various blends and diesel for CE and BE is shown in fig. 6. The first one is in-cylinder combustion temperature is approximately higher than 1600 °C, nitrogen molecules begin to take part in the reaction and thus produce NO_x. The second one is the reaction time is enough for the previous statements,

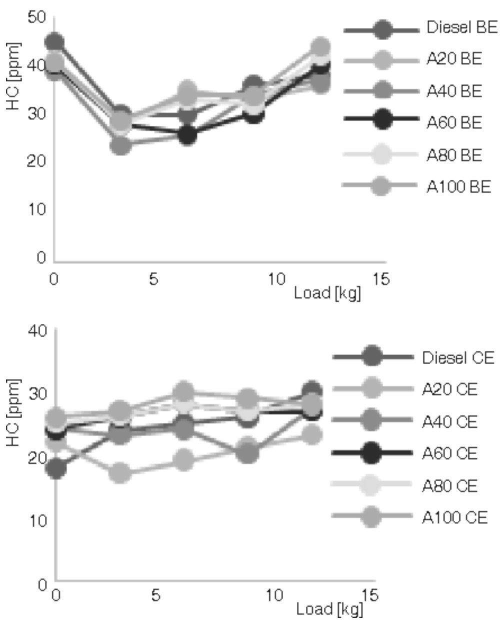

Figure 5. The variation of load *vs.* HC emission for BE and CE

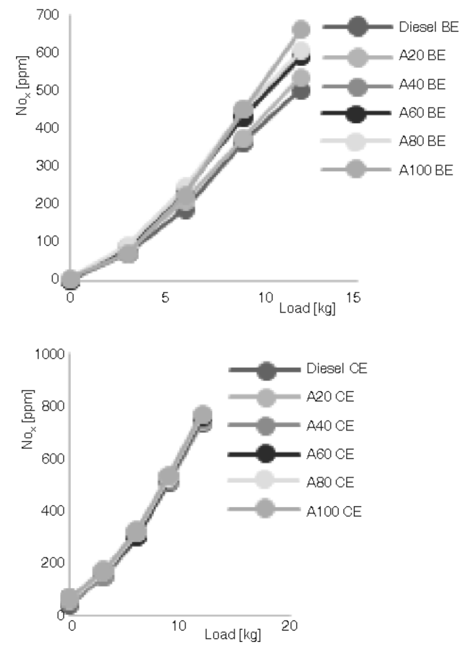

Figure 6. The variation of load *vs.* NO_x emission for BE and CE

and the highest NO_x emission are reduced. For coating engine, the NO_x emissions were increased in CE, for all the test fuels, due to the increased combustion temperature.

Smoke

The smoke of various biodiesel blends and diesel for CE and BE is shown in fig. 7. Among the different blends, A20 for CE showed much lower smoke emission than that of neat diesel and uncoated engine. It is observed that A20 in CE is decreased by 39.16% when compared to that of Neat diesel and BE. This is due to complete combustion.

Conclusions

The main results obtained from the experimental investigation for test fuels are summarized.

- The CE operation resulted in lower BSFC values for all the test fuels including petroleum based diesel fuel operation. This result related to the thermal efficiency of the engine increases with the CE.

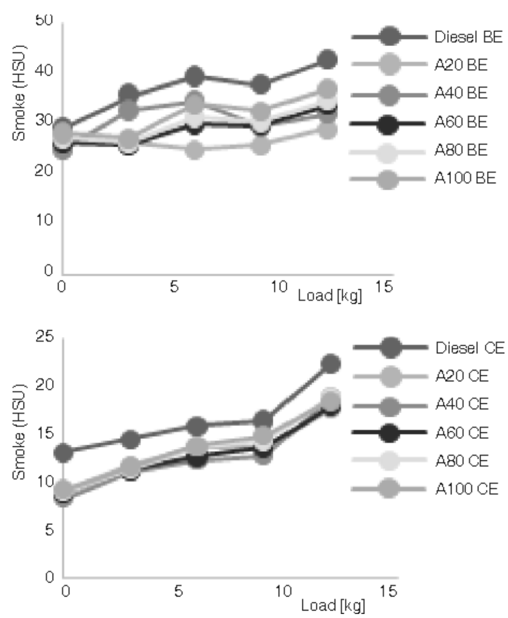

Figure 7. The variation of load *vs.* smoke for BE and CE

- CO and HC emissions were fairly reduced when substituting diesel fuel with biodiesel. Besides, CO emissions were considerably decreased and HC emissions were also generally decreased for both diesel and all biodiesel fuel blends in the CE.
- The NO_x emissions were also increased in CE, for all the test fuels, due to the increased combustion temperature.
- Smoke values were decreased almost in proportion to biodiesel concentration in the blend. Therefore it is concluded that 20% AME blended with the 80% of Neat diesel can be used as an alternate fuel in LHR engine without any modifications.

Nomenclature

BE – uncoated engine
CE – coated engine
CR – compression ratio
EGR – exhaust gas recirculation
HSU – Hartridge smoke unit
LHR – low heat rejection

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