

Experimental Study on Thermal Barrier Coated Diesel Engine Performance with Blends of Diesel and Palm Biodiesel

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ABSTRACT

Energy conservation and efficiency have been the quest of engineers concerned with internal combustion engine. 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 engines aim to do this by reducing the heat lost to the coolant. For current work a ceramic coated twin cylinder water-cooled diesel engine using blends of diesel and palm biodiesel as the fuel was evaluated for its performance and exhaust emissions. In recent years, Considerable efforts were made to develop and introduce alternative renewable fuel, to replace conventional petroleum-base fuels. Here, the diesel engine was insulated by Partially Stabilized Zirconia (PSZ) as ceramic material attaining an adiabatic condition. The cycle average gas temperature and metal surface temperature are higher in adiabatic engine. For the present study the biodiesel was prepared in laboratory from non-edible vegetable oil (Palm oil) by transesterification process with methanol, where potassium hydroxide (KOH) was used as a catalyst. An experimental investigation of the performance of a ceramic coated engine was carried out with palm bio-diesels and its blends, the results were compared to the experiment done with the conventional petroleum diesel. Multi cylinder vertical water cooled self-governed diesel engine, piston, top surface of cylinder head and liners were fully coated with Partially Stabilized Zirconia (PSZ). Experimental test set-up was developed in laboratory. The stationary diesel engine was run in laboratory at a medium speed, variable load condition experienced in most urban driving conditions and various measurements like fuel flow, exhaust temperature, exhaust emission measurement and exhaust smoke test were carried out. The results indicate improved fuel economy and reduced pollution levels for the Thermal Barrier Coated

(TBC) engine. The fuel properties of biodiesel such as kinematic viscosity, calorific value, flash point, carbon residue and specific gravity were found. Results indicated that Bio-diesels had lower brake thermal efficiency mainly due to its high viscosity compared to diesel. For biodiesel fuel, the exhaust gas temperature increased with increase in power and amount of biodiesel. However, during performance test it showed reasonable efficiencies, lower smoke, SO₂, PM (particulate matter) and CO with some increase in emission of oxides of nitrogen. Biodiesel also increased efficiency in reducing particulate emissions. Regulated emissions and performance data were generated, and a detailed emission was performed. Fuel properties were close to the standard limit for diesel fuel. The use of palm biodiesel resulted in lower emissions of unburned hydrocarbons, carbon monoxide, and particulate matter, with some increase in emissions of oxides of nitrogen.

INTRODUCTION

Energy flows and energy efficiencies in the operation of a modern automobile are expressed in terms of simple empirical relations [1]. One purpose is to convert any internal combustion engine energy into useful work. The overall energy use depends on two factors, vehicle load and power train efficiency. The former depends on speed and acceleration and key vehicle characteristics such as mass. The latter depends on heat-engine thermodynamic efficiency, and engine and transmission frictions.

NEED OF LOW HEAT REJECTION ENGINE

Energy conservation and efficiency have been the quest of engineers concerned with internal combustion engines. From the heat energy of the fuel offered by diesel engine goes one-

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third to the coolant, one-third to exhaust and leaving only about one-third as useful power output [2]. 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 engines aim to do this by reducing 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 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. A large number of studies on performance, structure and durability of the Thermal Barrier Coated (LHR) engine have been carried out [3,4,5,6,7,8,9,10,11,12,13,14,15,16,17]. Although promising the results if the investigations have been somewhat mixed. Most have concluded that insulation reduces heat transfer, improves thermal efficiency, and increases energy availability in the exhaust. However contrary to the above expectation some experimental studies have indicated almost no improvement in thermal efficiency and claim that exhaust emissions deteriorated as compared to those of the conventional water-cooled engines. An attempt will be made here to review the previous studied to look into future possibilities of the LHR engine from the viewpoint of combustion, heat transfer and emission.

ADIABATIC ENGINE

In thermodynamics, an adiabatic processes defined as a no heat loss process (heat transfer, $Q=0$). An adiabatic engine is a system where $Q = 0$ when the system is working. Generally, it is difficult to have adiabatic engine in practice. However, an adiabatic engine has no conventional cooling and strives to minimize heat loss. The adiabatic engine combustion chamber is made of material which allows the operation of the engine combustion with minimum heat loss. The hot or insulated high temperature component includes piston, cylinder head, valves, cylinder liner and exhaust manifold. Additional power and improved thermal efficiency from an adiabatic engine are possible because, thermal energy, normally lost to the cooling water and exhaust gases, is converted into useful power through the use of high temperature materials and a small gas turbine.

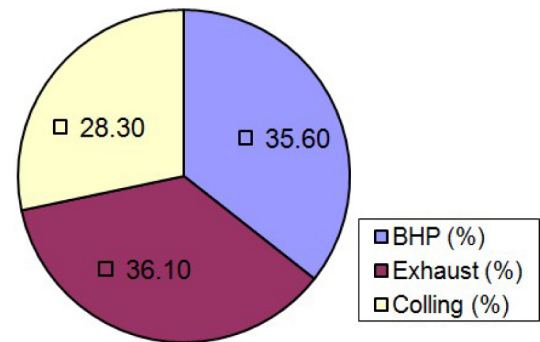


Figure 1. Base Engine.

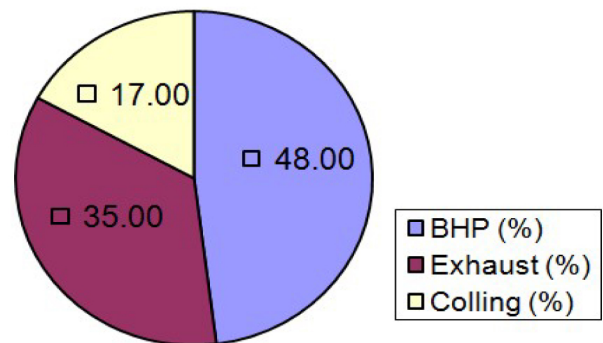


Figure 2. Adiabatic Engine.

Fundamentally, the adiabatic engine is more efficient than conventional diesel engine because it converts the fuel heat into additional useful output. This can be clearly seen from the energy balance diagram of various configurations as shown in figure.

Figure - 1 shows a conventional turbocharged diesel engine where the heat to B.P., heat carried by cooling water (water cooled engine) and heat carried away by exhaust gases is 33% in each. Figure - 2 represents the energy balance of an insulated engine (high temperature components) combined with turbo-compounding. This system further increases useable energy and proportionally decreases waste energy. Therefore, the potential for increasing the useful work of the same amount of fuel is higher for adiabatic, turbo-compound engines [2].

By reducing energy losses and by eliminating the need for conventional cooling system the adiabatic engine improves fuel economy and reduces the weight and volume appreciably for the same engine output. The high temperatures of combustion chamber walls of an adiabatic engine provide high compression-charge temperatures and reduce an ignition delay considering the high level temperature at which the adiabatic engine functions, the emission except NO_x are also reduce [2].

ENGINE COATINGS

There are three main types of coatings, and their names are self-explanatory. Thermal-barrier coatings hold heat in, heat-dissipating coatings let heat out, and low-friction coatings remove power-robbing and heat-inducing friction. There are also a few coatings that are purely cosmetic-they look good, very durable and clean up easily. Virtually every part on a car can be coated, from the suspension to the pistons.

TBC - THERMAL BARRIER COATINGS

The most commonly used TBC is a ceramic-based material that's applied to the top of the piston and to the combustion chamber and valve faces in the cylinder head. The TBC holds more heat in the chamber, instead of letting it dissipate through the piston, valves and head (where it is then absorbed by the cooling system). This theoretically increases cylinder pressure and pushes harder on the piston, making more power. The TBC also protects the aluminium piston from the intense heat, so the air/fuel mixture can be leaned slightly for maximum power without burning through the piston. And, since the amount of heat radiated into the rest of the engine is reduced (since it's contained in the chamber), the operating and oil temperatures of the engine come down. This is also beneficial to the piston rings, improving their radial tension and sealing ability. TBCs are also used on intake and exhaust ports and headers to improve scavenging and lower the under hood temperature.

EFFECT OF INSULATION

The combustion chamber wall temperature of an LHR engine is higher than that of a conventional water-cooled engine. Hence the charged air in a cylinder absorbs heat emanating from the high temperature chamber wall. Therefore the charged air expands, this lessening the amount of intake air. However if the increase in power output is to be realized, a turbocharger using higher exhaust energy and which increase the amount of intake air, or better still, a turbo-compound system that recovers exhaust energy and converts it into additional power should be connected with the LHR diesel engines. The results of investigation of Suzuki et al [3] on an uncooled turbocharged engine shows that the excess air ratio decreases by about 1% to 7.6% compared to that of water cooled, turbocharged base engine.

They have also carried out performance tests using the LHR engine insulated only at the exhaust port and found that the excess air ratio increased by 2% to 4.2%. The investigation of Moore and Hoehne [4] indicates a similar result. The results of Miyairi et al [5] on the other hand, show that cooling the liner with water even in the case of a naturally aspirated insulated engine can moderate the deterioration in volumetric efficiency. The results of many past investigations on combustion show decrease in the proportion of premixed combustion due to the shortening of the ignition delay and an

increase in the proportion of diffusion combustion. The rate of heat release in the diffusion combustion phase shows a decreasing trend from the early to middle period and lengthening of the subsequent after-burning period.

The decrease in volumetric efficiency and shortening of ignition delay seem to be two of the reasons for the slow and deteriorating combustion. The investigation of Alkidas indicates that poor air - fuel mixing is one of the reasons for degraded combustion in the case of LHR engine [18, 19]. The investigation of Noetal has clearly shown that the increase in viscosity of the burning gases as one of the major causes for the poor mixing rate, which is responsible for the degraded combustion.

PLASMA COATING SPECIFICATION

The thermal barrier coating of Zirconia (ZrO_2) is selected because of its better wear resistance, low thermal conductivity, high thermal shock resistance and high melting point (about 2800 °C) [20]. Plasma process parameters for zirconium oxide (ZrO_2) are:

1. Material specification: -22 ± 5 Microns
2. Stabilizer agents Bond coat: NiAl (Ni-95%, Al-5%)
3. Coating thickness: 500 Microns
4. Power required: 32.5 KW
5. Voltage: 65 V
6. D. C. current: 500Amp.
7. Plasma generating gas: Argon (Ar)
8. Powder deposition distance: 70 to 90 mm
9. Powder feed rate: 20-25 Grams / min
10. Pressures: 120 Psi
11. Plasma process type: D. C. Arc

BIO DIESEL

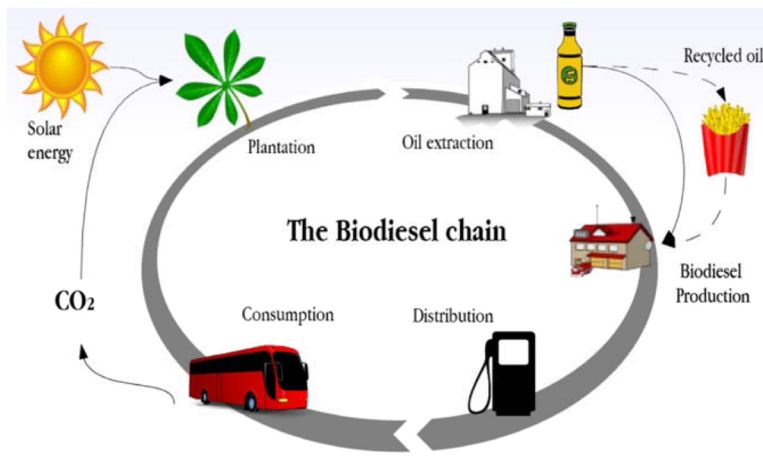


Figure 3. Biodiesel chain.

For the past few decades, a lot of effort has been made to reduce the dependency on petroleum fuels for power generation and transportation all over the world. Among the proposed alternative fuels, biodiesel have received much attention in recent years for diesel engines and could be one remedy in many countries to reduce their oil imports [22, 23, 24].

Biodiesel have many advantages over regular diesel as renewable and domestically produced energy resources. Moreover, they are recognized as environmentally friendly alternative fuels because previous studies have shown that there is a substantial reduction of CO, unburned hydrocarbons and particulate matter emission, when they are used in conventional diesel engines [25]. Biodiesel is an alkyl (e.g. methyl, ethyl) ester of fatty acids made from a wide range of vegetable oils, animal fat and used cooking oil via the transesterification process. Moreover, biodiesel has been used not only as an alternative for fossil diesel. Bio diesel is considered to be a candidate alternative to diesel in order to decrease the use of conventional diesel. It is expected that the use of ethanol as a gasoline-blending component can reduce the amount of petroleum-fuel imports by up to 10-15% [26]. Moreover, the use of Biodiesel can also increase farmer's incomes, because it can be produced domestically from many kinds of agricultural products such as sugar cane, molasses or cassava root. This success of Diesel-Biodiesel blending has led to interest in the use of oxygenated compounds as emissions reducing additives in diesel fuel. Moreover, the use of Biodiesel, particularly biomass-derived biodiesel, can result in significant savings in carbon dioxide emissions.

This approach offers a “no regrets” policy that reduces potential future risks associated with climate change, and it has the added benefit of economic development [27, 28]. Generally, Biodiesel can be blended with diesel with no engine modifications required. These can result in fuel

instability due to phase separation. Prevention of this separation can be accomplished in two ways: by adding an emulsifier, which acts to suspend small droplets of biodiesel within the diesel fuel, or by adding a co-solvent, which acts as a bridging agent through molecular compatibility and bonding to produce a homogenous blend. There are several studies concerning biodiesel production and utilization [29].

BIO DIESEL PRODUCTION

(See [Figure 4](#) after last section of paper.)

Biodiesel is commonly produced by the transesterification of the vegetable oil feedstock. There are several methods for carrying out this transesterification reaction including the common batch process, supercritical processes, ultrasonic methods, and even microwave methods.

Chemically, transesterified fatty acid (biodiesel) comprises a mix of mono-alkyl esters of long chain fatty acids. The most common form uses methanol (converted to sodium methoxide) to produce methyl esters as it is the cheapest alcohol available, though ethanol can be used to produce an ethyl ester biodiesel and higher alcohols such as isopropanol and butanol have also been used. Using alcohols of higher molecular weights improves the cold flow properties of the resulting ester, at the cost of a less efficient transesterification reaction. A lipid transesterification production process is used to convert the base oil to the desired esters. Any Free fatty acids (FFAs) in the base oil are either converted to soap, or removed from the process, or they are esterified (yielding more biodiesel) using an acidic catalyst. After this processing, unlike straight vegetable oil, biodiesel has combustion properties very similar to those of petroleum diesel, and can replace it in most current uses. A by-product of the transesterification process is the production of glycerol. For every 1 tone of biodiesel that is manufactured, 100 kg of glycerol are produced.

OBJECTIVE

The objective of this study is to understand the effect of insulation on the diesel engine performance with the use of diesel and blends Palm bio-diesel. The performance was checked with respect to performance characteristics of heat transfer, combustion and emission. The experiments were conducted on both petroleum diesel and blends of biodiesel at different load conditions and different speeds.

(See [Table 1](#) after last section of paper.)

EXPERIMENTAL SET UP

Engine was connected with an electrical dynamometer to measure the power output. The engine was instrumented to measure the parameter like fuel consumption, load and speed

of engine, cooling water temperature, inlet air & exhaust gas temperature with smoke density.

The engine test was carried out with constant speed of 1500 rpm and the load variation from no load to the maximum load conditions. At each operating stage the observations of various parameters were taken for both base engine and thermal barrier coated engine.

APPARATUS SPECIFICATIONS

1. Engine - Multi cylinder vertical water cooled self-governed diesel engine developing 10 HP @ 1500 rpm. Lubricating oil –20w/40. Lubricating oil quantity required 7Ltrs.
 2. Dynamometer 6 KVA capacity alternator coupled to the engine with load arrangement.
 3. Measurement -
 - a. Calibrated burette for fuel intake measurement.
 - b. Orifice meter - Fitted to the air inlet tank with water manometer for air intake measurement.
 - c. Multichannel digital temperature measurement at various points.
 - d. Exhaust gas calorimeter to measure heat carried away by exhaust gas.
 - e. Measure the water flow rate of engine jacket and calorimeter.
- (See Figure 5 after last section of paper.)

At each operating condition, the dynamometer load, speed and fuel and air flow were recorded after allowing time for the engine to stabilise. The uncertainties in the calculated characteristics with respect to measured parameter are shown in Table - 2.

(See Table 2 after last section of paper.)

TESTINGS

The following tests were carried out:

- Performance test
- Heat balance test
- Emission test

RESULTS AND DISCUSSION

FOR PERFORMANCE TEST

Specific Fuel Consumption (SFC)

It is observed from figure - 6 that the higher the flash point of biodiesel, the better atomization process will be performed.

The fuel consumption of engine was increased with increase in amount of biodiesel blends as shown in figure. It is found in case of coated engine that up to full load condition, the SFC is little more than that of the base engine and after full load the SFC was less. This is due to higher temperature due to which the combustion characteristics are improved.

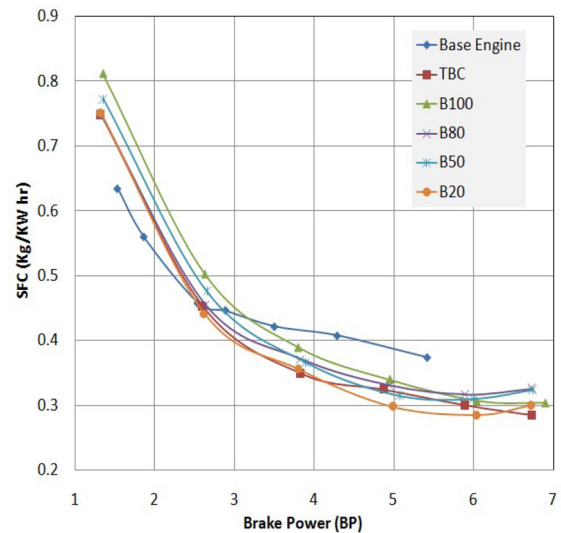


Figure 6. Variation in SFC with different brake power.

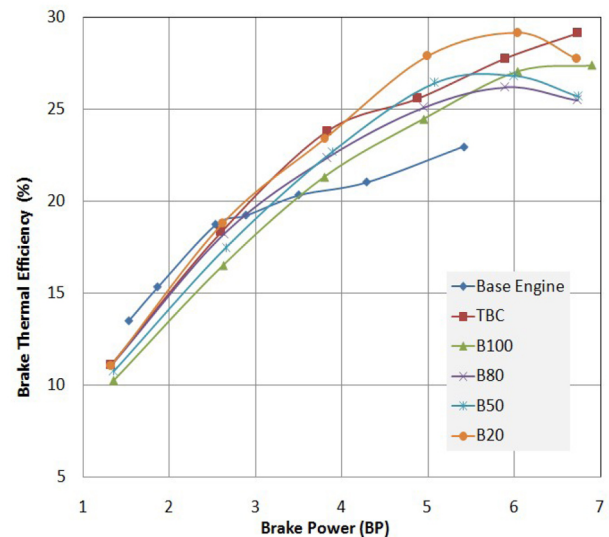


Figure 7. Variation in BTE with different brake power.

The percentage increase in fuel consumption of biodiesel blends (B20 to B100) ranged from 2 to 13 percent than diesel fuel due to decrease in calorific value of these fuels. The percentage increase in SFC was increased with decreased amount of diesel fuel in the blended fuels. This may due to higher specific gravity and lower calorific value of biodiesel fuel as compared with diesel fuel.