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Performance and Emission Evaluation of Turbo Charged Direct Injection Low Heat Rejection Engine Operated with Biodiesel

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***Abstract*— This study investigates the effects of turbocharger on the performance of a base-line (uncoated) and low heat rejection diesel engine using petro-diesel fuel and biodiesel prepared from pongamia and mahua oils. The performance is evaluated in terms of brake specific fuel consumption, brake thermal efficiency, volumetric efficiency and smoke emissions. For this aim, a turbocharged four-stroke direct injection base-line (uncoated) and certain engine components were coated with partially stabilized zirconia ceramic material to work like low heat rejection engine. All the tests were performed under constant speed with varying loads and fuel injection pressure left unaltrered. The evaluation of experimental data showed that the brake thermal efficiency of biodiesel was slightly higher than that of diesel fuel in both base-line(uncoated) and low heat rejection engine with turbocharged conditions, while biodiesel yielded slightly higher fuel consumption values. It was also observed that smoke emissions in the operations with biodiesel were lower than those in the operations with diesel fuel in all the cases. This study reveals that the use of biodiesel improves the performance parameters and decreases smoke emissions of the turbocharged engine compared to diesel fuel. It is suggested that lube oils of high viscosity are required for engines with low heat rejection type. Moreover, it is observed that resource is immaterial for the production of biodiesel once it meet the specified standards.**

Keywords—Direct injection diesel engine; thermal barrier coatings; low heat rejection; biodiesel; emissions

I. INTRODUCTION

Diesel engine are widely used as prime mover in medium and heavy-duty applications because of its relatively high fuel conversion efficiency, good mileage and capable of handling high loads in addition to release of lower levels of carbon monoxide (CO) and unburned hydrocarbons (HC) compared with gasoline engines. However, diesel engines are major sources of high particulate emissions and high oxides of nitrogen [1].

Undoubtedly, fossil fuel driven civilization brought huge wealth all over the world but at the same it has given rise to high pollutant emissions and dependence on import by the nations which have limited resources and thus losing hard earned revenue. This twin problems have made the combustion community to divert their research on the search for eco-friendly alternative fuels and to reduce dependence on imported oil reserves. To become self-sustainable sources from locally available resources should be encouraged.

In this direction, the credit first goes to inventor of diesel engine, he practically demonstrated that diesel or compression ignition engines can be run with vegetable based or animal based oils.

The seed oils that have attracted larger attention are sunflower, safflower, neem, peanut , cotton seed oils etc. However, these oils are serving in the domestic sectors for edible purposes. Therefore, it is imminent to exploit non-edible oils for producing diesel like fuel. The non-edible oils have been produced from mahua, pongamia, jatropha seed etc.

The high viscosity and low volatility of raw vegetable oils are generally considered to be the major drawbacks for their utilization as fuels in diesel engines. Due to these , direct use of plant based oils are prone for diesel injector coking, severe engine deposits, filter gumming problems, piston ring sticking, and thickening of the lubricating oil.

The high viscosity of vegetable oils deteriorates the fuel atomization and increases exhaust smoke. The low volatility leads to oil sticking to the injector or cylinder walls, resulting in deposit formation. However, these effects can be eliminated or reduced through esterification of the oil to form monoesters. Even though many techniques such as pre-heating , blending, micro emulsification and transesterification have adopted . Among these methods, process of transesterification removes glycerol from the triglycerides and replaces it with radicals from the alcohol used for the conversion process. This process decreases viscosity and improves the Cetane number and heating value. These monoesters are known as biodiesel. This helps in totally modifying the properties of parent vegetable oils and allowing its direct use in engines to replace petro-derived diesel with biodiesel.

It is observed through heat or energy balance tests on modern DI (direct ignition) diesel engines, about 15-25% of the fuel chemical energy input is rejected to the cooling system (water or oil) through the walls of the combustion chamber. Furthermore a major part 30-40%, of the fuel chemical energy input is lost through the exhaust gases finally exiting into the atmosphere with the temperature much higher than ambient. This fact has motivated extensive research into ways of improving the efficiency of engines (reduce fuel consumption), by thermal insulation of the

combustion chamber leading to lower heat losses to the coolant. And also the desire to increase thermal efficiency or reduce fuel consumption of engines makes it tempting to adopt higher compression ratios, in particular for diesel engines, and
reduced in-cylinder heat rejection. This has given rise to concept of adiabatic or semi-adiabatic engines and such engines have been named as low heat rejection engines (LHR).

To implement LHR Concept, certain engine components, such as piston, cylinder head, cylinder liners and exhaust valves, were provided with thermal barrier coatings (TBC). 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. Thermal barrier coatings are usually composed of a bond coat (NiCrAl) as an oxidation resistant layer and stabilized Zirconia as a top coat that provides thermal insulation toward metallic substrate.

Insulating the combustion chamber components of LHR engine can reduce heat transfer between in-cylinder gas and cylinder liner. The LHR concept is based on suppressing heat rejection to the coolant and recovering the energy in form of useful work. Few important advantages of LHR engines are improved fuel economy, reduced engine noise, higher energy in exhaust gases and multi-fuel capability of operating low Cetane fuels [2].

Average in-cylinder gas temperatures increase due to insulation in LHR engines. In compression stroke around TDC in-cylinder gas temperature increases by 250K in LHR engine in comparison to base-line (uncoated) engine. The known advantages of LHR diesel engines are different from base-line (uncoated) diesel engines in four ways:
(a) Ignition delay period shortens
(b) Diffusion burning period increases while premixed burning period decreases
(c) Total combustion duration increases
(d) Heat release rate in diffusion burning period decreases.

Although, transesterification makes the fuel properties of vegetable oil closer to petroleum diesel fuel, the viscosity of vegetable oil esters (biodiesel) is still higher (approximately 2 times) than that of petroleum diesel fuel. Biodiesel can be heated to reduce its viscosity further, so biodiesel can be used more efficiently in diesel engines. The concept of a LHR engine is believed to be useful in this regard. The increased in-cylinder gas and cylinder liner temperatures of the LHR engine make possible the usage of biodiesel without preheating. So the energy of biodiesel can be released more efficiently.

1.1 Low Heat rejection Engine:

The concept of low heat rejection (LHR) engine aims to reduce the heat transferred to cooling system. So this energy can be converted to useful work. Some of the major advantages of LHR engines are as follows: Better fuel economy, increased engine life, reduction in HC, CO and PM emissions, and lower combustion noise due to reduced pressure increasing rate, increased exhaust gases energy and ability of operating low Cetane fuels.

1.2 Various forms of LHR:

- Ceramic coated piston- low degree of insulation.
- Ceramic coated piston, cylinder head and liner.
- Air gap insulated piston engine.
- Air gap insulated piston and air gap insulated liner engine.
- Air gap insulated piston, air gap insulated liner and ceramic coated cylinder head engine- high degree of insulation.

There have been many studies about LHR engines and biodiesel usage in base-line(uncoated) diesel engines in the literature. However, there have not been many studies about biodiesel usage in LHR engines. So, this area has not been well understood.

A large number of studies on performance, structure and durability of the LHR engine have been carried out since Kamo and Bryzik presented a new concept of the LHR engine combined with the turbo compound system. Although promising the results of 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 expectations 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 [3].

It was reported that insulating the combustion chamber walls of the engine, which results in an increase in flame temperature, should significantly decrease combustion generated irreversibilities and, consequently, may improve the second law efficiency[4].

Morel et al. indicate that the higher temperatures of the insulated engine cause reduction in the in-cylinder heat rejection, which is in accordance with the conventional knowledge of convective heat transfer [5]. Woschni developed a universally acceptable heat transfer model for diesel engine to account for heat transfer coefficient under different temperature conditions [6].

Havstad et al. developed a semi-adiabatic diesel engine and reported an improvement ranging from 5 to 9% in ISFC, about 30% reduction in the in-cylinder heat rejection [7] .
A single-cylinder diesel engine with Superni-90 coated piston top and cylinder liner of which had a maximum engine power of 3.68kW and a compression ratio of 16:1. They used raw jatropha and pongamia oils and esterified jatropha oil as fuels. They found that the performance of the LHR engine improved, nitrogen oxide (NOx) levels decreased and exhaust gas temperatures were increased with all three non-edible vegetable oils in comparison with diesel fuel. They also found that the combustion parameters of the non-edible vegetable oils were within reasonable limits and revealed that non-edible vegetable oils can be successfully utilized as substitute fuels in a LHR diesel engine [8].
Thring states that comparison of SFC between baseline and LHR engine should be done carefully, because reducing the heat rejection affects other engine operating parameters such

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as volumetric efficiency, air-fuel mixing etc, which in turn affect fuel consumption. Hence it is felt that, comparison between the two engines should be made at same engine operating conditions and same engine operating parameters. In general, it has been reported that fuel consumption of, naturally aspirated LHR engine is in the range of 0 to 10% higher, turbocharged LHR engine in the order of 0 to 10% lower and turbo compounded LHR engine in the order of 0 to 15% lower, when compared with the conventional cooled engine.

Volumetric efficiency is an indication of breathing ability of the engine. It depends on the ambient conditions and operating conditions of the engine. Reducing heat rejection with the addition of ceramic insulation causes an increase in the temperature of the combustion chamber walls of an LHR engine. The volumetric efficiency should drop, as the hotter walls and residual gas decrease the density of the inducted air. As expected all the investigations on LHR engine show decreased volumetric efficiency. The deterioration in volumetric efficiency of the LHR engine can be prevented by turbocharging, and that there can be more effective utilization of the exhaust gas energy [10-12].

Performance and emission characteristics of a partially insulated Compression Ignition engine is investigated. They employed partial insulation on the combustion chamber the cylinder head, valves and piston crown was coated with 0.225mm thick alumina (Al_2O_3). Their results concluded that the Brake Thermal Efficiency (BTE) has increased by 2% compared to conventional engine and Specific Fuel Consumption (SFC) of the engine is reduced [13].

The introduction of new crops to agriculture would lead to an improvement in the biological and environmental condition of soils, water, vegetation and landscapes, and increasing biodiversity. They can be converted by first-generation biofuels technologies (combustion, ethanol from sugar and starch crops, and biodiesel from oil crops) or the second-generation biofuels (hydrolysis or synthesis of ligno-cellulosic crops and their residues to liquid or gaseous fuels such as hydrogen). A large potential and opportunity could be expected from the production of fuels from microalgae extraction which I would characterize as the third generation. They can produce at least ten times more biomass than land crops per unit area; they can be grown in saline, brackish or waste waters in ponds or in bioreactors and can be converted to oil, ethanol or hydrogen[14]. Biomass is:

- Storable;
- Transportable;
- Convertible;
- Available and affordable; and
- Always with positive energy balance.

1.3 Thermal Barrier Coatings:
Zirconia (Zirconium Oxide, ZrO2 -Y2O3 stabilized), is an extremely refractory material. It offers chemical and corrosion inertness to temperatures well above the melting point of alumina. The material has low thermal conductivity. It is electrically conductive above 600°C and is used in oxygen sensor cells and as the susceptor (heater) in high temperature induction furnaces. With the attachment of platinum leads, nernst glowers used in spectrometers can be made as a light emitting filament which operates in air.

Fig.3.1. Zirconium Oxide coated piston and head

1.3.1 Key Properties of Zirconium Oxide:

- Use temperatures up to 2400°C
- High density
- Low thermal conductivity (20% that of alumina)
- Chemical inertness
- Resistance to molten metals
- Ionic electrical conduction
- Wear resistance
- High fracture toughness and high hardness.

Table 1.1 Engineering Properties:

Density, gm/cc	6
Elastic Modulus ,GPa	200
Hardness, kg/ mm^2	1300
Thermal Conductivity, W/m°K	2
Coefficient of Thermal Expansion, 10^{-6}/°C	10.3

1.4 Methyl esters of vegetable oils-Biodiesel:
Biodiesel is produced by combining vegetable oil or animal fat with an alcohol, mostly methanol, in the presence of a catalyst through a chemical process known as *transesterification*. The advantages, benefits of using biodiesel, raw materials (both edible and non-edible), its production methods are well understood and documented [14].

For the present studies, two types of non-edible oils-Pongamia and Mahua oils were selected for preparation of corresponding methyl esters or biodiesel.The method followed are in line with the literature [14,15].

1.4.1. Mahua Oil:
Madhuca indica—commonly known as madhuka, yappa, mahuda, mahua, mauwa, mohwa, hippe, butter tree, mahwa, mahula, or elupa—belongs to the family Sapotaceae and grows up to 21 m high. This deciduous tree is distributed mainly in India. The kernels are 70% of seed by weight. Seeds content includes 35% oil and 16% protein. Main fatty acids are palmitic acid (16–28.2%), stearic acid (20–25.1%), arachidic acid (3.3%), oleic acid (41–51%), and linoleic acid (8.9–13.7%).

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1.4.2. Pongamia Oil:

Pongamia pinnata (L.) Pierre, P. glabra Vent., Cytisus pinnatus L., Derris indica (Lam.) Bennett, and Galedupa indica Lam.— commonly known as karanja, pongam, coqueluche, Vesi Ne Wai, vesivesi, hongay, and honge—belong to the Leguminaceae family and are widely distributed in tropical Asia. The tree is drought-resistant, tolerant to salinity, and is commonly found in East Indies, Philippines, and India. The karanja tree grows to a height of about 1 m and bears pods that contain one or two kernels. The kernel oil content varies from 27% to 39% and contains toxic flavonoids, including 1.25% karanjin and 0.85% pongamol. The fatty acid composition consists of oleic acid (44.5–71.3%), linoleic acid (10.8–18.3%), palmitic acid (3.7–7.9%), stearic acid (2.4–8.9%), and lignoceric acid (1.1–3.5%).

The present experimental studies aimed at observing the LHR engine with two types of non-edible based biodiesel with turbocharger incorporated for further improvement.

For this purpose, a single cylinder Kirlosker make direct injection (DI) diesel engine was converted to a LHR engine and the effects of biodiesel usage in the LHR engine on the performance characteristics and emission characteristics were investigated experimentally. A turbo charger and biodiesel made from two sources-pongamia and mahua oils were adopted.

2.0. EXPERIMENTAL PROGRAMME

2.1 Steps involved in the Production of Biodiesel:

2.1.1. Purification:

The vegetable oil is filtered to remove dirt, charred food, and other non-oil material often found in the oil. Water is removed because its presence causes the triglycerides to hydrolyze to give salts of the fatty acids instead of undergoing transesterification to give biodiesel. At home, this is often accomplished by heating the filtered oil to approximately 120 °C. At this point, dissolved or suspended water will boil off. When the water boils, it spatters. To prevent injury, this operation should be done in a sufficiently large container (at most two thirds full) which is closed but not sealed.

2.1.2. Neutralization of free fatty acids

A sample of the cleaned oil is titrated against a base-line(uncoated) solution of base in order to determine the concentration of free fatty acids (RCOOH) present in the vegetable oil sample. The quantity (in moles) of base required to neutralize the acid is then calculated.

2.1.3 Transesterification:

During the esterification process, the triglyceride is reacted with alcohol in the presence of a catalyst, usually a strong alkali (NaOH, KOH, or Alkoxides). The main reason for doing a titration to produce biodiesel, is to find out how much alkaline is needed to completely neutralize any free fatty acids present, thus ensuring a complete transesterification. Empirically 6.25 g / L NaOH produces a very usable fuel. One uses about 6 g NaOH when the vegetable oil is light in colour and about 7 g NaOH when it is dark in colour.

The alcohol reacts with the fatty acids to form the mono-alkyl ester (biodiesel) and crude glycerol. The reaction between the biolipid (fat or oil) and the alcohol is a reversible reaction so the alcohol must be added in excess to drive the reaction towards the right and ensure complete conversion.

2.1.4. Dual step process:

Experiment in the lab closely agrees with the reported literature that the presence of high FFA makes transesterification reaction difficult because of the formation of soap with alkaline catalyst. In the present set of experiments, the alternative route of using acid catalyst was adopted for biodiesel production from Karanja oil.

In context of the present series of tests, the high FFA Karanja oil was first converted to esters in a pre-treatment process with methanol using acid catalyst (H_2SO_4). A Bronsted acid such as H_2SO_4 is used for methyl esterification of FFA. The reaction was conducted at 65 ^{0}C with MeOH/oil at molar ratios from 1:3 to 1:10 and an acid catalyst concentration of 0.5%w/v of oil. Esterification was continued till the acid value was lowered and remained constant. Subsequently, the alcohol layer was removed from the pre-treated oil before the second step alkaline-catalyzed transesterification.

The pre-treated oil contains water and acid catalyst that need to be removed before alkali-catalyzed transesterification. The oil layer was separated from the mixture before alkali-catalyzed transesterification. At the first step, oil was preheated to 65 ^{0}C and the mixture of methanol and NaOH was added to the oil. The reaction was carried out with MeOH/ oil at molar ratios from1:3 to 1:10 and catalyst concentration of 1%w/v of oil at 65 ^{0}C, which is the optimum condition for Karanja oil.

2.1.5. Transesterification chemistry:

The alcohol/catalyst mix is then charged into a closed reaction vessel and the oil or fat is added. The system from here on is totally closed to the atmosphere to prevent the loss of alcohol. The reaction mix is kept just above the boiling point of the alcohol to speed up the reaction and the reaction takes place. Recommended reaction time varies from 1 to 8 hours, and some systems recommend the reaction take place at room temperature. Excess alcohol is normally used to ensure total conversion of the fat or oil to its esters. Care must be taken to monitor the amount of water and free fatty acids in the incoming oil or fat. If the free fatty acid level or water level is too high it may cause problems with soap formation and the separation of the glycerine by-product downstream.Since natural oils are typically used in this process, the alkyl groups of the triglyceride are not necessarily the same. Therefore, distinguishing these different alkyl groups, we have a more accurate depiction of the reaction:

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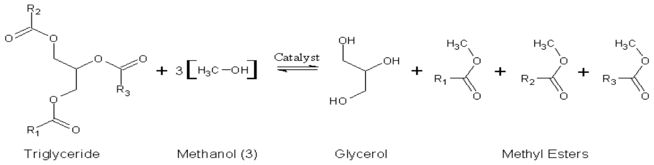


R_1, R_2, R_3: Alkyl group, long carbon chains that are too lengthy to include in the diagram.

Fig. 2.1. Transesterification reaction [14]

2.1.6 Separation:

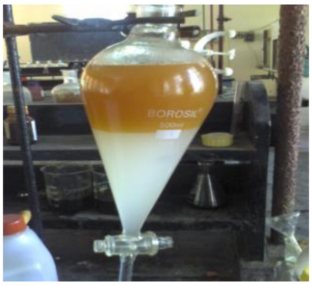
Once the reaction is complete, two major products exist: glycerine and biodiesel. Each has a substantial amount of the excess methanol that was used in the reaction. The reacted mixture is sometimes neutralized at this step if needed. The glycerine phase is much denser than biodiesel phase and the two can be gravity separated with glycerine simply drawn off the bottom of the settling vessel. In some cases, a centrifuge is used to separate the two materials faster.

2.1.7. Final process (water wash):

After separating from the glycerine, the biodiesel is sometimes purified by washing gently with warm water to remove residual catalyst or soaps, dried, and sent to storage. In some processes this step is unnecessary. This is normally the end of the production process resulting in a clear amber-yellow liquid with a viscosity similar to parodies. In some systems the biodiesel is distilled in an additional step to remove small amounts of colour bodies to produce a colourless biodiesel

Pongamia oil /Mahua kept for reaction.

Separation of glycerine from biodiesel



Water wash and separation of biodiesel from water

Final product (biodiesel)

Fig.2.2 Steps of preparation of biodiesel

2.2 Turbocharger:

Turbocharging is one of the configurations of supercharging by density of charge to the engine can be increased by pressurization. For this purpose, unlike in superchargers, the compression is done by means of expanding exhaust gases before leaving to the atmosphere. Watson and Janota [16] provides one of the more comprehensive treatises on turbochargers. They describe a turbocharger as a turbine driven compressor that is used to increase the air flow rate into an internal combustion engine. Turbochargers are efficient in that the turbine utilizes the exhaust gas energy that is typically rejected to the atmosphere in the case of a naturally aspirated engine. For the turbocharger to operate efficiently, the mass flow rate of exhaust gases passing through the turbine must equal the sum of the compressor air mass flow rate and the fuel mass flow rate added. An exhaust waste gate can be used to avoid over-speeding the turbocharger when compensating for high cylinder pressures of a turbocharger operating over a wide speed and load range [16]. The exhaust waste gate's purpose is to bypass the excess engine exhaust gas past the turbine to ensure an energy balance between the compressor, engine, and turbine. The energy balance of the power produced by the turbine must be equal or be slightly greater than the power consumed by the compressor and bearing losses.

There are many types and configurations of turbochargers [1]. Fig 2.3a and Fig 2.3b show different types turbochargers. The two most common turbocharger configurations are (1) a centrifugal compressor and a radial turbine, or (2) a centrifugal compressor and an axial turbine. Fig 2.3a and Fig 2.3b show examples of the two common turbocharger configurations. The figures are good representations of the two common configurations and show the cut-away views of the main components for each turbocharger.

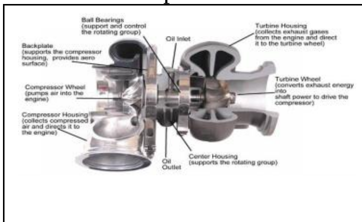


Figure 2.3 Cut-away view of centrifugal compressor and radial turbine turbocharger

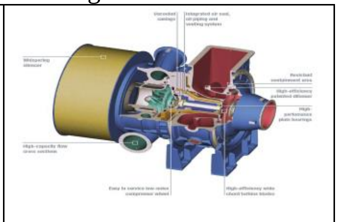


Figure 2.4 Cut-away view of centrifugal compressor and axial turbine turbocharger

3.0 EXPERIMENTAL PROGRAMME

3.1. The Experimental Setup:

A single cylinder, four stroke, constant speed, water cooled, direct injection diesel engine is used for the experiments conducted. The technical specifications of the engine are as below.

Table: 3.1. Specifications of the test engine

No. of cylinders	one
Bore	80.0 mm
Stroke	110.0 mm
V_{disp}	552.94 cc
Rated output	3.68 kW (5.0 hp)
Connecting rod length	230.0 mm
Compression ratio	16.5
Speed	1500 rpm
Injection advance	27° BTDC

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Single cylinder diesel engine. | Turbine Type Airflow Meter | Exhaust Gas Smoke Meter

Figure 3. Major Equipment used

Smoke density of the exhaust gas of the engine was measured when the engine was run at different injection pressures, with different fuels (diesel and biodiesel) and with TBC and without TBC using KOMYO smoke meter.

3.2 Experimental Procedure:

- Before starting the engine, the injection pressure was set at 250 bar and turbocharger was installed to engine and the engine was loaded with the piston without thermal barrier coating.
- Then, the engine was started using diesel as fuel and is allowed to run for around 20 minutes so as to attain steady state condition.
- The digital indicators were switched on for reading the temperatures (exhaust gases, inlet and outlet water) sensed by thermocouples.
- Time taken for the consumption of 30cc of fuel was measured with the help of a stop watch and burette. Time taken for 1 m^3 of air intake was measured using turbine type airflow meter.
- Readings were taken from the engine at no load, 20%, 40%, 60%, 80% and at full load, applied on the engine with the help of a hydraulic dynamometer. Keeping speed as constant (1500rpm).
- All the readings that are taken when the engine was run at 250 bar injection pressure, without thermal barrier coating using diesel as fuel were tabulated and various performance characteristics such as fuel consumption, brake thermal efficiency, mechanical efficiency, volumetric efficiency etc. were calculated.
- Above procedure was repeated, readings were tabulated and various performance characteristics were calculated when the engine was run without TBC using diesel as fuel.
- After the completion of experiments with diesel, at 250 bar injection pressures, without TB coated piston, the engine was loaded with the piston and cylinder head with Zirconia coating.
- After loading the engine with thermal barrier coated piston and cylinder head the engine was run with diesel as fuel.
- Now, the engine was run, the readings were tabulated and various performance characteristics were calculated.
- After the completion of experiments with diesel, with and without TBC, fuel lines to the engine were changed, new fuel filter was assembled to avoid the deviation of readings when the engine is run with biodiesel.
- Now, the engine was run using biodiesel (pongamia and mahua methyl esters-respective biodiesels).
- Engine was run with biodiesel and different readings were taken and tabulated. Various performance characteristics were calculated similarly as above.
- Now, the piston and cylinder head with thermal barrier coating (PSZ) was loaded into the engine and the above experiments were conducted on the engine, readings were tabulated and performance characteristics such as fuel consumption, brake thermal efficiency, mechanical efficiency, etc. were calculated.
- Every time, smoke density of the exhaust gases exiting coming out of the engine was measured using KOMYO smoke meter for all the above experiments.
- Lube oil , cooling water and exhaust gas temperatures were also noted.
- All the results were plotted and compared.

Table: 3.2. Comparison of important properties of biodiesel(Pongamia and mahua) with petro-diesel.

Parameter	Petro-diesel	Pongamia Biodiesel	Mahua Biodiesel
Density(ρ)gm/cc	0.8325	0.885	0.895
KinematicViscosity @ 40^0C,(cSt)	2.5	4.2	4.6
Cetane Number	50	55.84	54
Lower Calorific Value,kJ/kg	43,200	39,300	38,800
Flash Point,(open cup), @ 40^0C,	58-62	174	130

4.0 RESULTS AND DISCUSSION

A single cylinder diesel engine's performance is studied by running it with biodiesel produced from the pongamia and mahua based oils and is compared with neat petro-diesel fuel run engine operation.

The engine was provided with thermal barrier coating with partially stabilized zirconia(PSZ) ceramic material, for certain components of engine and a turbocharger is employed to observe the effect on performance and emissions of conventional diesel engine. Constant speed performance tests were performed to observe certain parameters such as specific fuel consumption, thermal efficiency, exhaust gas temperature and smoke emissions.

4.1. Experimental Results:

Two sets of experiments were conducted on single cylinder direct injection diesel engine with and without thermal insulated components using diesel and biodiesels as

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fuels. In each set of tests readings of engine power, fuel consumption, exhaust gas temperature, and so on, were taken for zero to full load at constant speed.

4.1. Performance tests with different fuels under naturally aspirated condition of engine:

To begin with and for generating base line results, performance tests were conducted on chosen engine under naturally aspirated condition. From the Fig.4.1, it can be observed that the values of brake specific fuel consumption values are on higher side for engine operation with biodiesel across all loads due to its higher density. It can also be seen that that brake thermal efficiency values are very close to each other with pongamia based biodiesel values are marginally on the lower side.

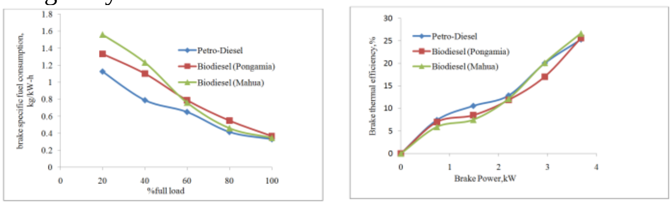

Figure 4.1 Comparison of brake specific fuel consumption and brake thermal efficiency with biodiesel fuels under naturally aspirated condition of engine

4.2. Performance tests on turbocharged incorporated engine with different fuels:

The next set of experiments were conducted with turbo charger to observe its effect on the performance of engine. The objective of incorporating turbocharger is to supply more mass of air to allow near complete combustion of fuels with high density.

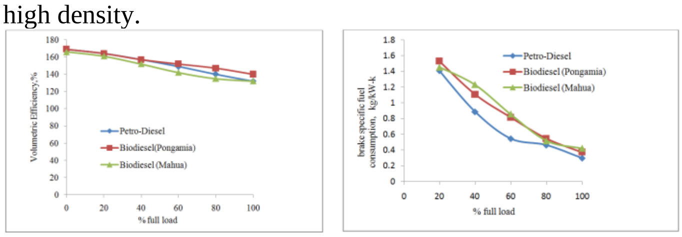

Figure 4.2 Comparison of brake specific fuel consumption and brake thermal efficiency with biodiesel fuels under naturally aspirated condition of engine.

It can be observed that the values of volumetric efficiency values have been significantly increased with turbo charger. Also, the brake specific fuel consumption values marginally increased. This is due to the fact that with more fuel being allowed to take part in combustion.

4.3.Performance tests on turbocharged incorporated LHR engine with different fuels:

Since the performance has been improved with turbocharger, the experiments were performed with engine in which certain components were insulated, i.e. LHR engine.

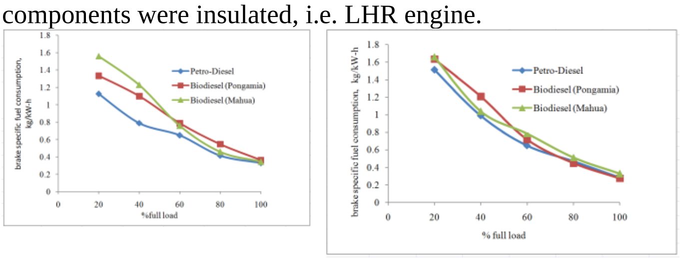

Figure 4.3 Comparison of brake specific fuel consumption for naturally aspirated engine and LHR with turbocharger engine.

It can be seen that the brake specific fuel consumption values are diverging in naturally aspirated condition except at full load. However, in case of LHR with turbo charger, the values more close to each other indicating the performance of engine with biodiesel are approaching diesel fuel operation.

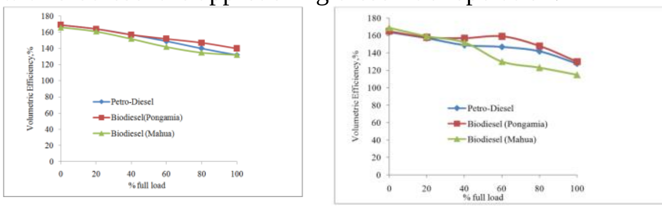

Figure 4.4 Comparison of brake specific fuel consumption for naturally aspirated engine and LHR with turbocharger engine.

One important observation can be drawn when LHR engine with turbocharger was operated. The volumetric efficiency values were higher side in engine without thermal barrier coatings or uncoated engine. Whereas the values have been significantly reduced to lower side in case of LHR engine. Since the engine was maintained hot , the values have become little lower.

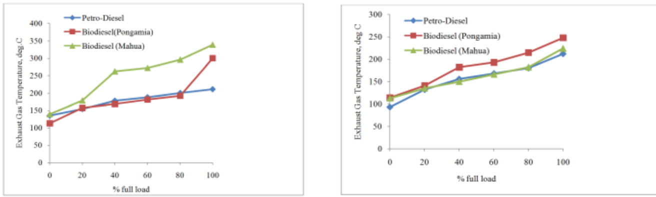

Figure 4.5 Comparison of exhaust gas temperature without and with coated engine components but with turbo charger.

Fig.4.5 depicts the engine exhaust gas temperatures for engine without and wit coated components but with turbo charger. It is obvious that the temperatures are higher in uncoated engine when compared with LHR engine. It is indicating that the LHR engine is helping in complete combustion. Moreover, as the temperatures are lower , engine can adopt higher compression ratios to derive more out of the engine as the engine with turbo charger is yielding higher volumetric efficiencies.

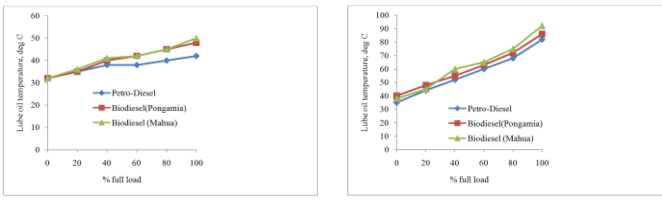

Figure 4.6 Comparison of engine lube oil temperature without and with coated engine components but with turbo charger.

Fig.4.6 illustrates the lube oil temperatures when engine is provided with and without coated components. The temperatures in case of LHR engine operation were steeper and higher that compared to uncoated engine. This is necessitating the fact that LHR engine requires hih viscous lube oils to sustain and provide good lubrication especially under prolonged hours of operation and higher load operation.

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4.4 Measurement of Smoke density:

Comparison of smoke densities of turbocharged uncoated engine and low heat rejection engine (LHR) are shown in Fig.4.7. As can be seen from the figures, the smoke density of the LHR biodiesel is significantly less compared to the LHR and standard diesel engine. With LHR engine operation both biodiesels and diesel results in lower smoke emissions due to boost pressure better combustion. Also, the engine was provided with turbocharger, it has facilitated for complete combustion.

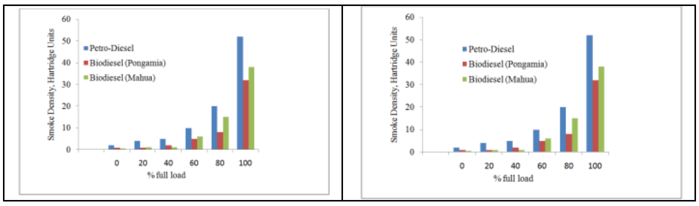

Figure 4.7 Comparison of engine lube oil temperature without and with coated engine components but with turbo charger.

CONCLUSIONS

The experimental studies conducted as detailed above yielded following conclusions:

- Because of higher fuel density and lower heating value, biodiesel showed slightly high brake specific fuel consumption (BSFC) for turbocharged operations in comparison with diesel fuel. The BSFC decreases for both tested fuels in the turbocharged operation.
- The brake thermal efficiency of the engine with diesel fuel are higher than those with biodiesel for turbocharged operations. The turbocharger application to the engine causes considerable increases in the brake thermal efficiency with biodiesel when compared to diesel fuel. The rate of increase in the brake thermal efficiency with biodiesel is higher than that with diesel fuel for turbocharged operation. The values of brake thermal efficiency in the cases of diesel fuel and biodiesel approach each other in turbocharged operation.
- In the turbocharged uncoated engine operation the use of biodiesel yields slightly higher brake thermal efficiency, while in turbocharged LHR operation the use of biodiesel improves brake thermal efficiency further compared with the use of diesel fuel.
- The lube oil temperatures were observed to be higher in engine operation with coatings, hence special lube oils are required to be used.
- The use of biodiesel improves the performance and lower the exhaust smoke emissions of the turbocharged engine better compared with the use of diesel fuel.
- The performance of engine with both biodiesels are near to each other, hence, it may be concluded that it is immaterial as far as source of raw oil is concerned.

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