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Effect Of Pongamia Methyl Ester (PME) On Performance and Emission Characteristics On Turbocharged Low Heat Rejection (LHR) Di Diesel Engine With Mullite As A Thermal Barrier Coating (TBC)

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Abstract ***- Heat loss to the cooling system of engine and to the surrounding itself plays a remarkable role in the power output and in turn the thermal efficiency, which can be maximised up to the limitation of Second Law of Thermodynamics. In return reduction in heat loss to the surrounding directly increases the desired work output and also the thermal energy carried away by the exhaust gas which must be utilized to produce some useful work. For the desired results, tests were carried out on a LHR modified engine i.e. by thermally insulating engine components like piston head, cylinder head and valves with a 0.5 mm thickness of mullite ($3Al_2O_3.2SiO_2$) as a TBC over a 150 µm thickness of NiCrAlY as a bond coat with and without turbocharger using PME fuel. TBC application improves the BSFC in turbocharged engine with PME fuel by 16% when it is compared with natural aspirated engine with PME fuel and by 20% when compared with standard engine, Turbocharged (TU) LHR engine gives the difference of 3% in brake thermal efficiency (BTH) when compared with standard engine and reduction of 24% and 38% in CO and HC emissions respectively were obtained in LHR TU engine when compared to standard diesel engine at full load. LHR - Low Heat Rejection; TBC - Thermal Barrier Coating; $3Al_2O_3.2SiO_2$ - Alumina silicate; PME - Pongamia methyl ester; BSFC - Brake specific fuel consumption; BTH - Brake thermal efficiency.***

Key Words –**Low Heat Rejection (LHR), Mullite, Pongamia Methyl Ester (PME), Thermal Barrier Coating (TBC), Turbocharger.**

I. INTRODUCTION

The major parameters always been discussed in case of internal combustion engines include energy conservation, fuel consumption and thermal efficiency. Diesel engines generally rejecting each one third of the fuel energy to coolant and in exhaust. Thus only one third of fuel energy is utilized as work output. Heat rejection to the coolant can be reduced by thermally insulating the engine components i.e. converting the conventional engine into LHR engine, thus a maximum thermal efficiency to the limit of Second Law of Thermodynamics can be attained. Pioneer work was done in diesel engine technology by Kamo and Bryzik [1] and different surfaces of combustion chamber was thermally coated with material like silicon nitride. The effect of insulation on engine performance, heat transfer characteristics, combustion and emission characteristics were studied in detail by S. Jaichandar and P. Tamilporai [2], the material used were Partially Stabilized Zirconia (PSZ) and ZrO2 and the investigations leads to lowering of fuel consumption by 2 to 17 % and thereby increasing the thermal efficiency in the range of 2 to 2.7% as compared to conventional engine. Ekrem Buyukkaya et al. [4] also found similar results and maximum reduction in BSFC is 6% as compared to conventional diesel engine. Mullite is thermally more stable than YSZ at high temperatures and is much more oxygen-resistant even at high temperatures. The mismatch of low thermal coefficient of mullite is compensated with the 150 µm thickness of NiCrAlY bond Coat. Tests performed with both materials by Jeffery J. Swab et al. [8] which showed that the life of the mullite coating in the engine is significantly longer than that of zirconia. Above 1273 K, the thermal cycling life of mullite coating is much shorter than that of YSZ. Mullite coating crystallizes at 1023–1273 K, accompanied by a volume contraction, causing cracking and de-bonding. Mullite has excellent thermo-mechanical behavior below this range as expressed by Jeffery J. Swab et al. [8] and D. R. Clarke et al. [9].

Properties	Mullite
Melting point	2123 K
Thermal conductivity(λ)	3.3 W /(m K) (1400 K)
Young's modulus (E)	30 GPa (293 K)
Thermal expansion coefficient (α)	$5.3x10^{-6}$/K (293–1273 K)

Table 1. Properties of mullite [13].

Lower heat rejection from combustion chamber through thermally insulated components causes an increase in available energy that would increase the in-cylinder work and the amount of energy carried by the exhaust gases, which could be also utilized. Adnan Parlak et al. [3] declares that thermal insulation increase the in-

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cylinder temperatures leads to some improvement in exhaust emissions and it can be further reduced to a high extent by using biodiesel as an alternative fuel to diesel fuel, thus the exhaust emissions can be reduced to remarkable extent at the cost of slight decrease in efficiency in natural aspirated engine (NA) as fuel consumption of neat pongamia biodiesel is investigated as more than that of diesel by K. Sureshkumar et al. [5] and B. Rajendra Prasath et al. [7]. Thus the heat of biodiesel is efficiently released in LHR concept. Pongamia Methyl Ester is obtained from raw pongamia oil by basic transesterification process, saturated fatty acids in raw oil is converted to long chain esters with reduced viscosity than raw oil. Its calorific value is less and its density is 6% more than that of diesel, 12% of molecular oxygen present in PME reduces its calorific value compared to diesel fuel; and it still has twice the viscosity of diesel fuel. Table 2. Compares the some important properties that are measured by taking samples of esterified pongamia biodiesel and raw pongamia oil with that of conventional diesel fuel.

Fuel properties	Diesel fuel	Raw Pongamia oil	PME
Density at 22°C kg/m^3	832	913	848
Lower calorific value MJ/kg	43.62	37.3	38.8
Viscosity(cst) at 40°C	2.87	27.84	4.56
Cetane no.	50	37	50

Table 2. Comparison of Properties of Raw Pongamia Oil, Biodiesel (PME) and Diesel.

The increase in in-cylinder temperatures improves the exergy at exhaust and to convert this to mechanical work turbocharger can be incorporated. Also the high temperatures of combustion chamber reduces the density of air inducted thereby lowering its volumetric efficiency therefore engine requires a boost, which can be provided by turbocharger, it also compensates slight loss in thermal efficiency if NA engine was run on PME fuel. The LHR engine has been conceived basically to improve fuel economy by eliminating or reducing the size of the conventional cooling system and converting part of the increased exhaust energy into shaft work using the turbocharged system. S. Jaichandar et al. [2] and Adnan Parlak [3] found the increase in thermal efficiency by 2.5% and 3.5% respectively. At the cost of slight lowering of thermal efficiency biodiesel is exhibiting remarkable improvement in CO and HC emissions as investigated by B. K. Rajamanoharan et al. 2009 [10]. P. N. Shrirao [11] investigated 22% and 28% reduction in CO and HC emissions respectively. This work emphasizes the effect of PME fuel on performance and emission characteristics of LHR engine with mullite as TBC ceramic material with and without turbocharger. The LHR engine was fed with PME and results are compared with and without turbo charging system. This way PME operated TU engine compensates the high viscosity and density of biodiesel and reduction of major exhaust emissions are obtained simultaneously.

No. of cylinders	one
Stroke No	four
Bore	80.0 mm
Stroke	110.0 mm
V_{disp}	552.94 cc
Rated output	3.68 kW (5.0 hp)
Compression ratio	16.5:1
Injection advance	23° BTDC
Speed	1500 rpm

Table 3. Engine Specifications

II. EXPERIMENTAL SETUP

Crude oil extracted from *Pongamia pinnata* seeds was transesterified into PME with the best of 900 ml yield of neat biodiesel per litre of raw oil. Standard DI engine is investigated first with diesel fuel and then is converted to LHR DI diesel engine by installing mullite coated piston crown, cylinder head and valves. Experiments were carried out on LHR engine at 0, 25, 50, 75 and full load conditions with and without turbocharger using PME as a fuel and the results are compared with standard engine. The lubrication of turbocharger was done by lubricating the turbo shaft by main oil pump with the use of a oil pipe connected to pump and turboshaft. Nitrous oxides (NOx), carbon monoxide (CO), hydrocarbon (HC) were measured by NETEL gas analyzer.

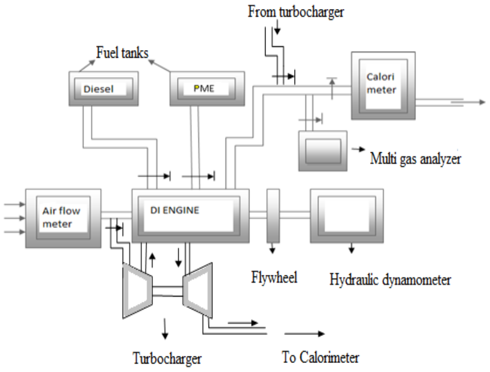

Fig 1. Schematic Diagram of Experimental Test Rig

III. RESULTS AND DISCUSSIONS

Long term experimental investigations were carried out on DI diesel engine in which the LHR version i.e. with mullite as a TBC of the engine was fuelled with the well

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prepared PME. Turbocharger was carefully attached and evaluation of BSFC, BTH, exhaust gas temperature and energy balance for LHR engine with and without turbocharger with PME fuel and is compared with that of LHR engine with diesel fuel. PME showed the reduction in CO and HC emissions, while NOx emissions are increased and reduction in BTH is observed which is compensated by the application of turbocharger, thus obtaining better performance than that of LHR engine with diesel fuel. Thus the final set up showed improved performance as well as exhaust emissions and not to be ignored heat loss to coolant is reduced with the effect of increase in thermal energy of exhaust gases.

A. Specific fuel consumption

In LHR version of engine with PME has 16% higher BSFC than that of LHR engine with diesel fuel at full load. The cause high fuel consumption with biodiesel at all loads may be attributed to the high density and low calorific value of PME than that of diesel. Figure 2 shows the comparative values of BSFC. LHR-TU operated engine with PME fuel showed the improvement in BSFC by 15% and 20% when compared with that of LHR-NA engine with diesel as a fuel and that of standard engine respectively. This reduction is mainly caused by the improvement in fuel atomization, air-fuel mixing and combustion characteristics of the fuel due to the high induction pressure and increased air charge in the cylinder of the diesel engine in TU operation, these factors collectively reduces the BSFC with the application of turbo charging.

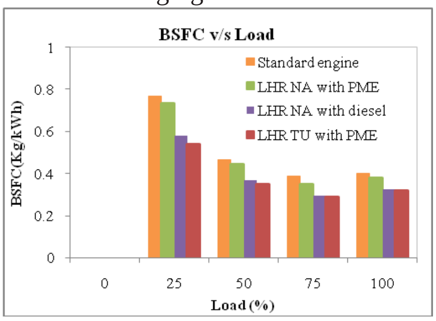

Fig 2. Specific Fuel Consumption.

B. Brake thermal efficiency

Though calorific value of biodiesel is lower than that of diesel (about 11%), but due to increase in fuel consumption, reduction in thermal efficiency obtained. Hence, the thermal efficiency of LHR engine with PME is lower than that of LHR diesel and found to be reduced by 3.36% at full load conditions. Figure 3 depicts the variation and comparison of BSFC against different loading conditions. Turbo charging utilizes the increased exhaust energy for which LHR concept is incorporated in the engine, giving rise to BTH, also the induction of air at high pressure assists the air fuel mixing, thus the makeup of reduction in BTH with biodiesel is made. Application of TBC reduces heat loss to coolant straight away improving work output and thus the efficiency. At full load conditions the difference of 3% in efficiencies of LHR-TU and standard engine with diesel fuel was observed.

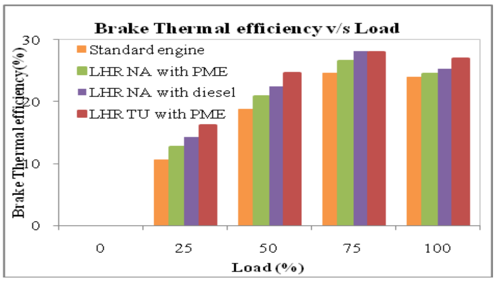

Fig 3. Brake Thermal Efficiency.

C. Carbon monoxide emissions

Figure 4 gives the variation of CO emissions with different loading conditions, steep rise in emissions can be seen at higher loads because as the fuel consumption increases comparatively less air is inducted which results in improper combustion, thus the application of turbocharger justifies the improvement in CO emissions as more mass of charge is inducted in combustion chamber, also the increased in-cylinder temperatures of LHR version of the engine and the oxygen content in PME fuel provides the near to complete combustion conditions of PME fuel. Combustion characteristics and conditions were remarkably improved with LHR TU operated engine as compared to LHR NA engine and standard engine. With PME fuel CO emissions in LHR TU engine were reduced by 8% and 24% as compared to LHR NA with PME fuel and standard engine at full load conditions, and PME fuel itself showed the drop of 11 % in CO emissions as compared to diesel fuel. LHR technology increases the in-cylinder temperatures causing better burning of fuel and oxygen content of PME assists the combustion which is more near to complete combustion as compared to diesel fuel without TBC.

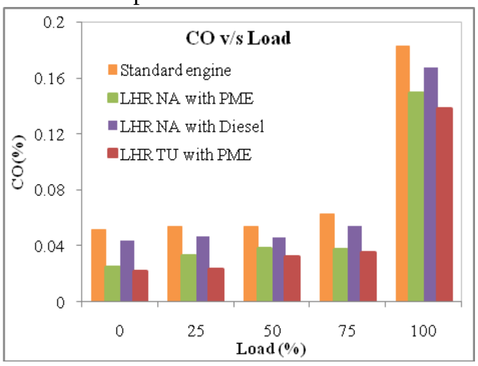

Fig 4. CO Emissions.

D. Nitrogen Oxide (NOx) emissions

Figure 5 depicts the variation of NOx emissions with loading conditions; concentration of NOx emissions is direct function of exhaust temperature. Use of biodiesel in LHR engine increases the NOx emissions by 21% as compared to LHR engine with diesel fuel at maximum loading conditions. increase in in-cylinder temperature due to ceramic coating leads to higher NOx, thus LHR engine provides higher NOx emissions and biodiesel itself contained good level of oxygen content provides

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favorable conditions for the formation of NOx, in addition to it more of the air i.e. more oxygen is inducted when LHR engine is operated with turbocharger thus providing more of the oxygen that too at higher temperatures leads to high Nox emissions. LHR TU engine with PME leads to 29.6% and 38% increase in NOx emissions compared to that of LHR NA diesel operated and standard engine respectively.

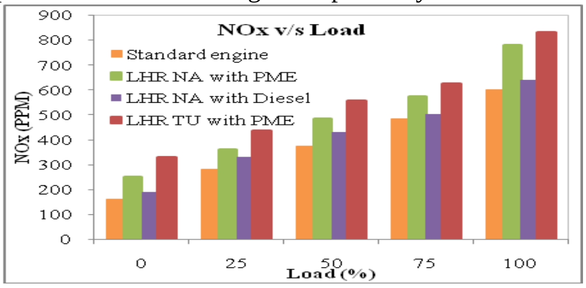

Fig 5. NOx Emissions

E. Hydrocarbon (HC) emissions

Combustion with PME is improved which results in remarkable drop in HC emissions as compared to that of diesel fuel, and is reduced by 19% with LHR engine at full load; this is due to the fact that PME as a biodiesel (esters) contains oxygen itself and high temperatures in LHR engine effectively using heat of biodiesel as compared to that of diesel fuel. Low thermal conductivity of mullite leads to higher temperatures in the gases and at the combustion chamber walls of the turbocharged LHR engine assisting in permitting the oxidation reactions to proceed close to completion and moreover oxygen content in PME biodiesel also leads to the same, and 38.57% reduction in HC emissions in LHR turbocharged operation is observed when compared with standard engine at full load conditions, as shown in Figure 6.

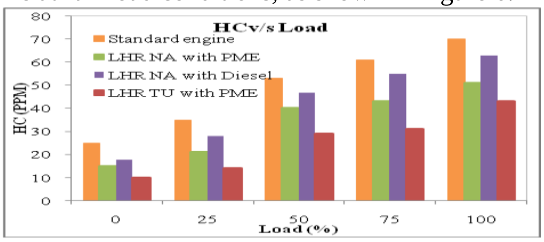

Fig 6. HC Emissions

F. Exhaust temperature

Low thermal conductivity of mullite retains the heat inside the combustion chamber leads to increase in exhaust gas temperature and improved combustion characteristics of PME fuel also plays the vital role in increasing the exhaust temperature. Figure 7 shows the increased fashion of exhaust temperature as more of the fuel is burnt per minute with the increase in load. LHR engine operated with PME fuel gives the increment 23% when compared with LHR NA engine with PME fuel at full load. LHR TU engine with PME showed the increment of 32 % and 37% when compared with LHR NA engine with diesel and with standard engine respectively at full load condition.

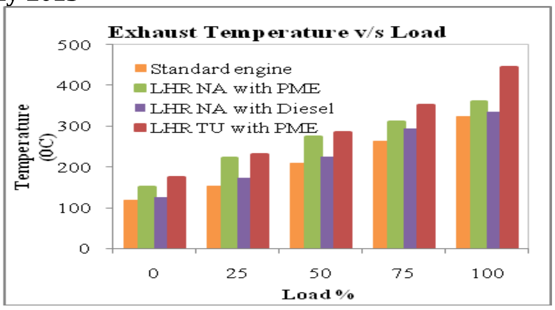

Fig 7. Exhaust Gas Temperature.

G. Heat Balance

Figure 8. Shows the investigation of heat balance of standard engine and LHR engine depicting the proportion of heat carried away by coolant and energy delivered to ambient surrounding as hot exhaust gases. It can be found from Figure 8. that heat retained by LHR concept is well utilized by turbocharger, as the proportion of work output is more and percentage of heat loss to the cooling system is also reduced.

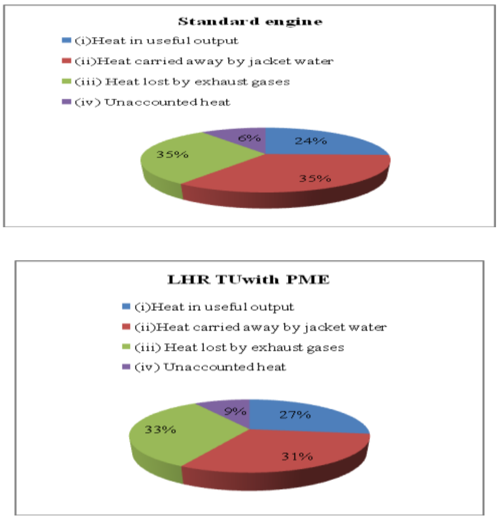

Fig 8. Heat Balance

IV. CONCLUSION

Biodiesel reduces the efficiency of LHR engine but reduces desired emissions, however NOx were always high with PME; but turbo charging is compensating the performance of PME and simultaneously emissions are drastically improved. Thus the thermal energy of exhaust gas was utilized to produce effective work. HC and CO emissions were reduced in LHR TU engine with PME. BSFC is improved by 20% compared to diesel fuel at full load. Improvement in thermal efficiency is direct effect of TBC application and utilization of exhaust energy by turbocharger to produce useful mechanical work.

APPENDIX

LHR – Low Heat Rejection.
TU – Turbocharged.
TBC – Thermal Barrier Coating.
NA – Natural aspirated.
PME – Pongamia methyl ester.

YSZ – Yttria Stabilized Zirconia.
DI – Direct Injection.

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REFERENCES

[1] R. Kamo, and W. Bryzik 1979 "Ceramics in heat engines."

[2] S. Jaichandar and P. Tamilporai. 2003 "Low Heat Rejection Engines – An Overview."

[3] Adnan Parlak, Halit Yasar, Osman Eldogan 2004 "The effect of thermal barrier coating on a turbo-charged Diesel engine performance and exergy potential of the exhaust gas."

[4] Ekrem Buyukkaya, Muhammet Cerit. 2007 "Experimental study of NO*x* emissions and injection timing of a low heat rejection diesel engine."

[5] K. Sureshkumar, R. Velraj, R. Ganesan 2008 "Performance and exhaust emission characteristics of a CI engine fueled with Pongamia pinnata methyl ester (PPME) and its blends with diesel."

[6] S.H. Chan and K.A. Khor 1999 "The Effect of Thermal Barrier Coated Piston Crown on Engine Characteristics."

[7] B. Rajendra Prasath, P. Tamil Porai, Mohd. F. Shabir 2010 "Two-zone modeling of diesel/biodiesel blended fuel operated ceramic coated direct injection diesel engine."

[8] Jeffery J. Swab and Paul J. Huang 2001 "Evaluation of monolithic ceramics and ceramic TBC for diesel engine."

[9] D. R. Clarke, C. G. Levi and A. G. Evans 2005 "Enhanced zirconia TBC systems"

[10] Avinash Kumar Agarwal, K. Rajamanoharan 2009 "Experimental investigations of performance and emissions of Karanja oil and its blends in a single cylinder agricultural diesel engine."

[11] P. N. Shrirao, A. N. Pawar. 2011 "Evaluation of Performance and Emission characteristics of Turbocharged Diesel Engine with Mullite as Thermal Barrier Coating."

[12] Imdat Taymaz 2006 "An experimental study of energy balance in low heat rejection diesel engine."

[13] L. J. Technology Pvt. Ltd.- Ceramic merchants.

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