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Research Article

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Combined effect of LHR coating and Pongamia oil methyl ester on combustion, performance and emission characteristics in a single cylinder DI diesel engine

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ABSTRACT

Increasing concerns over stringent emission norms in transportation sector and rapid consumption of the natural petroleum derivatives urged the researchers towards seeking alternative fuels such as biodiesel to be used in compression ignition engine. In the present investigation, Pongamia biodiesel was used in CI engine with Alumina ceramic coating of 0.3mm by thermal detonation spray method on the piston to enhance the combustion, performance and emission parameters. The Pongamia oil was transesterified and subjected to GC/MS and physio-chemical analysis to identify its compatibility in IC engines. The Brake thermal efficiency and Brake Specific Energy Consumption was found to decease with the addition POME concentration with diesel but LHR Alumina coating improved their performance between 4% and 9%. The combustion parameters like In-cylinder pressure and Rate of heat Release also showed significant improvement in the presence of LHR coating with POME blends as fuel. The UBHC, CO and Smoke emission was found to decrease with a marginal increase in NO_x for the LHR engine fuelled with POME blends.

Keywords: Pongamia biodiesel, LHR, Combustion, Performance, emission.

INTRODUCTION

Diesel fuel, the most economic power source for automobile and agricultural sectors is being consumed at a rapid at a tremendous rate. The increase in vehicle population and industrialization has led to the rapid depletion of this non-renewable energy source. Diesel fuel is consumed at a higher proportion than the gasoline fuel due to its fuel economy and lesser emissions. However the main drawback of the diesel engines is that the emission of high amount of Oxides of Nitrogen. Various researches are being carried out worldwide to compensate the depletion of conventional fuels and environmental effects by using biodiesel as the substitute fuel for diesel engines. Due to their high oxygen content, the biodiesel emission levels are very much reduced when compared with standard diesel fuel.
The effect on injection timing on combustion, performance and emission characteristics was evaluated using Karanja oil methyl ester. The results showed that retardation of injection timing by 3^0 increases the thermal efficiency by 8.2% and also reduces the Oxides of Nitrogen emission[9]. Investigation of performance, emission and combustion characteristics using blends of rapeseed oil and neat rapeseed oil showed a decrease in smoke opacity by 60% and increase in Brake Specific Fuel Consumption by 11% compared to diesel. The Carbon Monoxide emissions were lowered by 9% and 32% for 10% and 10% blends of biodiesel respectively. The ignition delay period was also found to be shorter for the neat rapeseed oil when compared to diesel fuel.[4]. Mahua oil ethyl ester was tested in a single cylinder Direct Injection diesel engine for performance and emission characteristics. The results showed an increase in brake thermal efficiency for mahua oil ethyl ester. The Carbon monoxide and hydrocarbon emission were reduced by 58% and 63% respectively when compared to diesel fuel[14].Even though biodiesel contributes less emission characteristics than petroleum diesel, their chemical and physical properties are

different from diesel fuel which makes them to suppress their performance. To achieve higher performance and reduced emissions better air fuel mixing is required which can be achieved by optimizing the injection parameters and modification of piston geometry. Pongamia oil methyl ester was tested for its effect on diesel engine with different combustion chamber geometries. The results indicated that Brake Thermal Efficiency for toroidal combustion chamber is higher than the other geometries, also reduction in emission of particulates, carbon monoxide and unburnt hydrocarbons was observed [8]. Due to the high viscosity and less calorific value of the biodiesel, they result in poor mixing of fuel with air, injector choking and lesser performance. These drawbacks can be rectified by employing Low Heat Rejection (LHR) concept. The main aim of an LHR engine is to reduce the amount of heat transferred to the coolant by coating the parts of combustion chamber with ceramic materials [1]. LHR engines are very significant when using biodiesel as the fuel. Partially stabilized zirconia coated LHR engine was investigated for performance, emission and combustion characteristics using diesel and biodiesel as the fuel. The analysis resulted an increase in brake thermal efficiency, NO_x emissions and particulate matter, while the fuel consumption reduced for LHR engine operating with biodiesel [16,21]

In this research work an attempt is made to combine the effects of piston bowl design, biodiesel and LHR concept to compare the combustion, performance and emission characteristics with the baseline conditions. The experiments were carried out in a Four Stroke DI diesel engine with a Shallow Toroidal Re-entrant Piston(STRP) geometry coated with Alumina(Al_2O_3) of 300 microns with 10% and 20% blends of Pongamia Oil Methyl Ester (POME10 and POME20).

Nomenclature and Abbreviations	
CI	Compression Ignition
DI	Direct Injection
BSN	Bosch Smoke Number
BSEC	Brake Specific Energy Consumption
BTE	Brake Thermal Efficiency
BMEP	Brake Mean Effective Pressure
UBHC	Unburned Hydrocarbons
CO	Carbon Monoxide
NO_x	Oxides of Nitrogen
BTDC	Before Top Dead Centre
STRP	Shallow Toroidal Re-entrant Piston
POME	Pongamia Oil Methyl Ester
POME10	10% POMEand 90% Diesel
POME20	20% POME and 80% Diesel
LHR	Low Heat Rejection
FFA	Free Fatty Acid
ROHR	Rate of Heat Release
FAME	Fatty Acid Methyl Esters

EXPERIMENTAL SECTION

2.1 Biodiesel Production

Pongamia oil was obtained from the kernels of Pongamia pinnata by crushing expeller method. 10 kg of Pongamia seed was procured from a small town near Kancheepuram, Tamil Nadu. The seeds were dried in the open surface for 48 hours to remove moisture. The dried seeds were emptied in a crushing expeller through which the Pongamia oil was extracted. 10 kilograms of Pongamia seed yielded 460 ml of crude oil.

Two stage transesterification i.e. acid catalysed esterification and base catalysed transesterification was carried out to reduce the viscosity of Pongamia oil. 2% of concentrated sulphuric acid was added to the raw Pongamia oil to reduce Free Fatty Acid from 14% to less than 2%. This procedure was followed by base catalysed esterification in which 250 ml of methanol was mixed with 4 grams of sodium hydroxide to form Sodium methoxide solution. 1 litre of treated Pongamia oil was mixed with sodium methoxide solution and maintained at 65^oC and was continuously stirred at 450 rpm for 2 hours. A settling period of 72 hours was allowed for the separation of Pongamia Oil Methyl Ester (POME) and glycerol. The obtained POME was placed in the rotary evaporator at 75^oC for 2 hours to remove the excess methanol and washed with distilled water for the removal of glycerol catalyst and soap. The pH value was maintained between 7 and 8 by continuously washing with distilled water and finally heated from 80^oC to 90^oC to remove excess water [3, 10-13].

Table 1. Physio Chemical properties of POME and Straight Diesel

Properties	Straight Diesel	POME	POME10	POME20
Density @ 15^0C(kg/m^3)	839	899	845	851
Kinematic Viscosity @ 40^0C (mm^2/sec)	3.02	5.41	3.47	3.92
Calorific Value(MJ/kg)	44.7	38.2	40.05	39.54
Flash point (^{0}C)	68	189	76	81
Fire point (^{0}C)	101	210	105	113
Cetane number	50	58	52	51
Acid value, mg KOH	0.11	0.51	0.21	0.26
Carbon residue (%)	0.1	0.02	0.11	0.12

The test fuels were prepared by blending 10 and 20% of POME with straight diesel and its physio-chemical properties were analysed to understand their suitability to be used in CI engine. The parameters like Density, Kinematic Viscosity, Calorific value, Flash point, Fire point, Carbon residue, Acid value and Cetane number were analysed and tabulated in Table(1). It was found that on addition of POME with diesel the Density and Kinematic viscosity increased by 7% to 8%. The calorific value of POME was found to be 38.2 MJ/kg and the blending of POME with diesel by 10% and 20% showed a marginal decrease by 10% and 11% respectively. The Cetane number was found to decrease significantly with the addition of Pongamia Oil Methyl ester [19-22].

2.2 Gas Chromatography /Mass Spectrometry

The Gas Chromatography and Mass Spectrometry was performed on POME using JEOL GCMATE II with a maximum resolution of 6000 and a calibrated mass Daltons double focusing data system. The Fig(1) shows the mass spectrum of POME in which the retention time for the compounds were between 14.97 minutes and 29.62 minutes and the compound names are given in Table(2) The analysis revealed that oleic acid at retention time 19.07 minutes was found in higher concentration. The GC/MS analysis revealed the presence of 8 prominent methyl esters i.e. at retention time 14.97, 16.93, 17.18, 17.98, 19.07, 19.2, 20.73 and 23.02 showed the presence of Methyl tridecanoate, Palmitoleic acid, Pentadecanoic acid, Oleic acid, Margaric acid, Arachidic acid and Palmitic acid respectively [6].

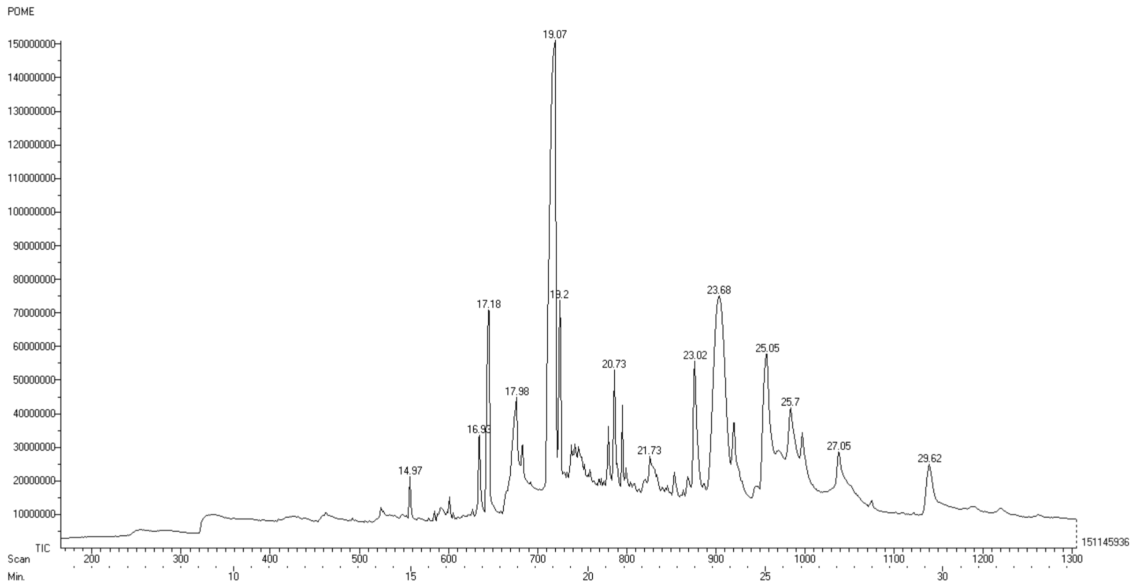

Figure 1. GC/MS mass spectrum of POME

Table 2. Fatty Acid Methyl Ester composition in POME

Ions	Retention time	Compound name	Common Name	Molecular formula
1244	14.97	Tridecanoic acid, 12-methyl, methyl ester	Methyl tridecanoate	$C_{15}H_{30}O_2$
1042	16.93	11- Hexadecanoic acid methyl ester	Palmitoleic acid	$C_{17}H_{32}O_2$
556	17.23	Pentadecanoic acid 13 methyl ester	Pentadecanoic acid	$C_{17}H_{34}O_2$
982	18.02	n-Hexadecanoic acid	Palmitoleic	$C_{16}H_{32}O_2$
297	19.07	10-Octadecanoic acid methyl ester	Oleic acid	$C_{19}H_{36}O_2$
510	19.22	Heptadecanoic acid 14-methyl-methyl ester	Margaric acid	$C_{19}H_{38}O_2$
810	20.73	11-Eicosenic acid,methyl ester	Arachidic acid	$C_{21}H_{40}O_2$
731	23.03	Hexadecanoic acid- butyl ester	Palmitic acid	$C_{20}H_{40}O_2$

2.3 LHR Engine development

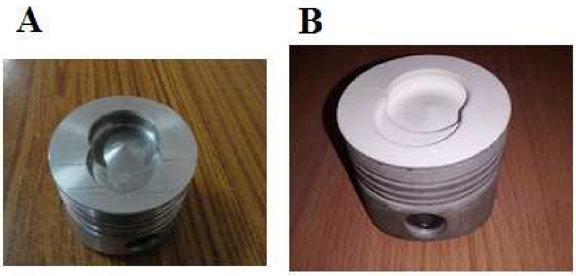

Figure 2. Pictorial view of the STRP without Alumina coating (A) & with Alumina Coating (B)

The STRP geometry is coated uniformly with alumina(Al_2O_3) of 0.3mm thickness using Thermal Detonation Spray coating method. The piston head is machined to reduce 0.3mm prior to the application of Al_2O_3 coating to maintain the standard dimensions of the test engine. The photographic view of the coated and uncoated piston is shown in Fig (2).

III. Experimental Setup

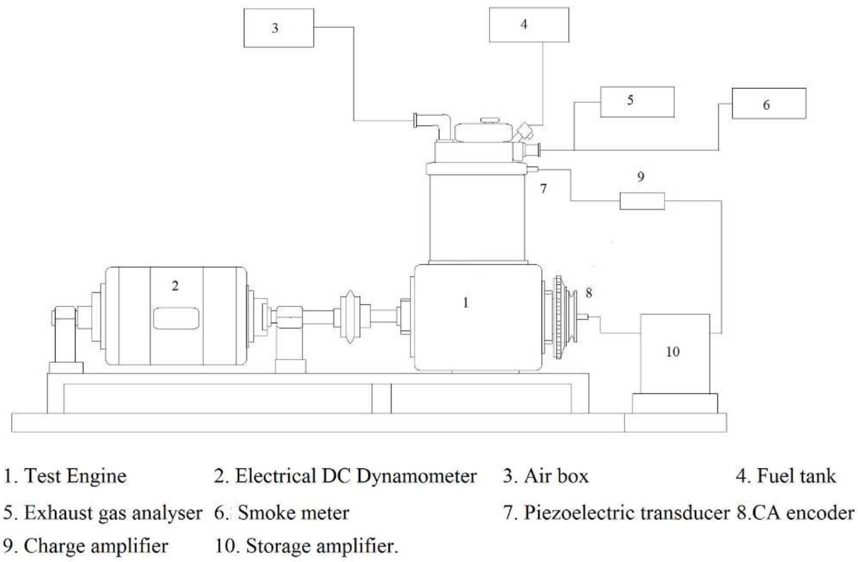

Figure 3. Schematic layout of the Experimental setup

Table 3. Technical specifications of the test engine

Engine Model	Greaves 5520
Engine Type	Single Cylinder, 4S, Direct Injection
Type of Cooling	Air cooled
Air Intake system	Naturally Aspirated
Bore(mm)	78
Stroke(mm)	68
Speed(rpm)	3000 - 3500
Rated Power	3.73 kW @ 3000 rpm
Cylinder capacity(cc)	325
Compression Ratio	18:1
Injection Timing	26^0 BTDC
Piston Geometry	Toroidal Piston geometry

The experimental layout of the investigation is shown in Fig (3). The engine used for the analysis was a Greaves engine 5520 model, 4 stroke direct injection diesel engine. The specifications of the technical data of the engine is given in Table (3). The loading of the engine was carried out in an Electrical DC Generator Dynamometer. The rate of fuel consumption was found using a 3 way stopcock and burette. The time taken for the consumption of 10cc of fuel was noted down using stopwatch. The emission analysis was done using a Crypton 290 5 Gas analyser and the concentration of CO, UBHC and NO_x emissions in the exhaust gas was found. The combustion study was carried out with the help of a piezoelectric transducer and crank angle encoder. The combustion pressure at every angle of the crank position was measured and recorded with the help of charge amplifier and data acquisition system.

RESULTS AND DISCUSSION

The variation of In-cylinder pressure with crank angle for full load operation on DSTRP, DLHR STRP, STRP and LHR STRP with POME10 and POME 20 blends respectively. The STRP combustion chamber with diesel fuel exhibited a maximum In-cylinder pressure of 50.5 bar whereas the LHR coated STRP showed a marginal improvement upto 52 bar with the same fuel which may be due to reduced heat transfer to the surrounding by the Alumina coating. POME10 and POME20 blended fuel for STRP showed a significant reduction in In-cylinder pressure due to poor premixed combustion phase and shortened ignition delay. The combined effect of biodiesel blends and LHR showed a positive increase in their corresponding In-cylinder pressures by 5% to 6% on comparison with non LHR coated piston. A similar trend was observed at low and part load operations of biodiesel and Alumina coated pistons.

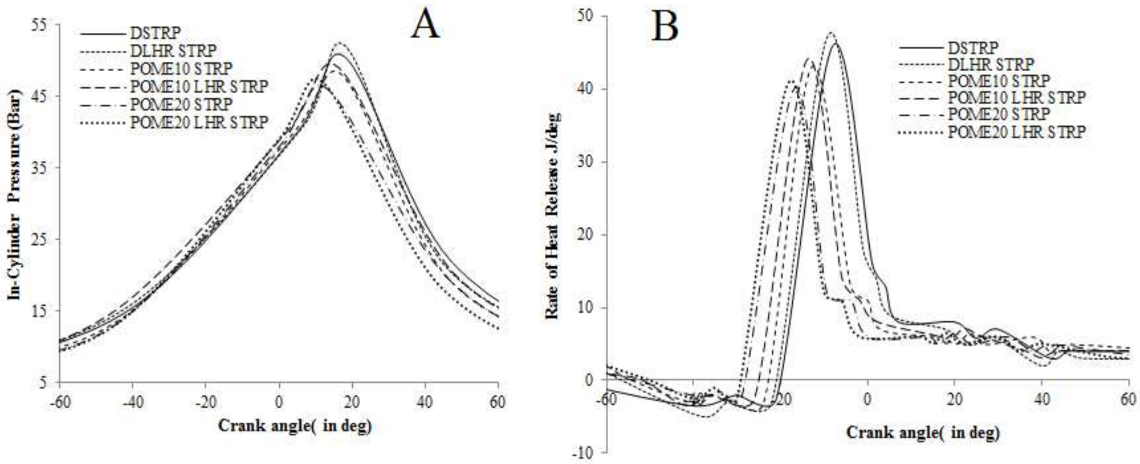

Figure 4. Variation of In-cylinder pressure and Rate of Heat release with Crank angle

Figure () shows the variation in rate of heat release for DSTRP, DLHR STRP, STRP and LHR STRP with biodiesel as fuel at full load condition. The STR piston with diesel fuel showed a maximum ROHR of 46 J/deg whereas the LHR Alumina coated STR piston exhibited 47.5 J/deg which may be due to reduced heat transfer rate by alumina coating. The STRP and LHR STRP with POME10 blend showed 43J/deg and 44 J/deg ROHR respectively which is 4% to 5% deceases in comparison with diesel fuel. As the blend ratio increased upto POME20%, the STR piston exhibited 40 J/deg whereas STR LHR piston exhibited 41 J/deg ROHR respectively which may be due to variation in ignition delay and poor premixed combustion phase where maximum quantity of heat is released [2].

The variation of the Brake Specific Energy Consumption(BSEC) with respect to Brake Mean Effective Pressure(BMEP) for diesel and LHR engine operating with diesel and biodiesel blends is shown in Fig(6). The BSEC shows a higher value for low loads and follows a decreasing trend with increase in load. At low load diesel engine operating with POME20 blend consumes higher energy of 24.86 MJ/ kW-hr, whereas for POME10 and diesel fuel it consumed 23.64 MJ/ kW-hr and 22.36 MJ/ kW-hr respectively. The LHR engine operating with Diesel fuel consumed less energy than the other blend at all loads.At full load condition the LHR engine operating in diesel fuel consumed 9.98 MJ/ kW-hr which is lower by 3.6%, 11.72% and 15.2% than Diesel engine running on diesel, LHR engine running on POME20 blend and diesel engine running with POME20 respectively and lower by 6.01% and 9.62% than LHR engine operating on POME10 and diesel engine running on POME10 blend respectively. This increase in energy consumption with biodiesel may be due to the reduced calorific value which needs more energy to produce the same power output.

Brake Thermal Efficiency(BTE) varying with BMEP for diesel engine operating with diesel fuel and biodiesel blends and LHR engine operating on diesel fuel and biodiesel blends is shown in Fig(7). At low loads the BTE for diesel engine was found to be 13.22% with diesel whereas it shows 12.65% and 12.08% with POME10 and POME20 blends. The BTE for LHR engine operating with diesel was found to be higher than the other fuelsat full load condition which gives a maximum efficiency of 29.63% which is higher by 2.7%, 4.4%, 6.8%, 8.87% and 11.11% than diesel engine running on diesel fuel, LHR engine operating on POME10, Diesel engine operating with POME10, LHR engine operating on POME20 blend and Diesel engine running with POME20 respectively. This increase in BTE in case of LHR engine may be due to the enhanced combustion and higher combustion chamber temperature [5].

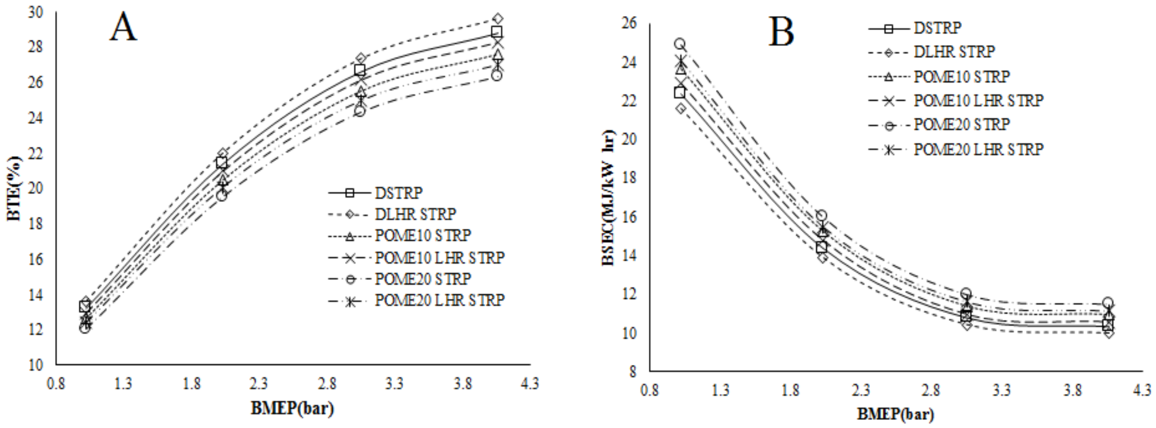

Figure 5. Variation of BSEC and BTE with BMEP

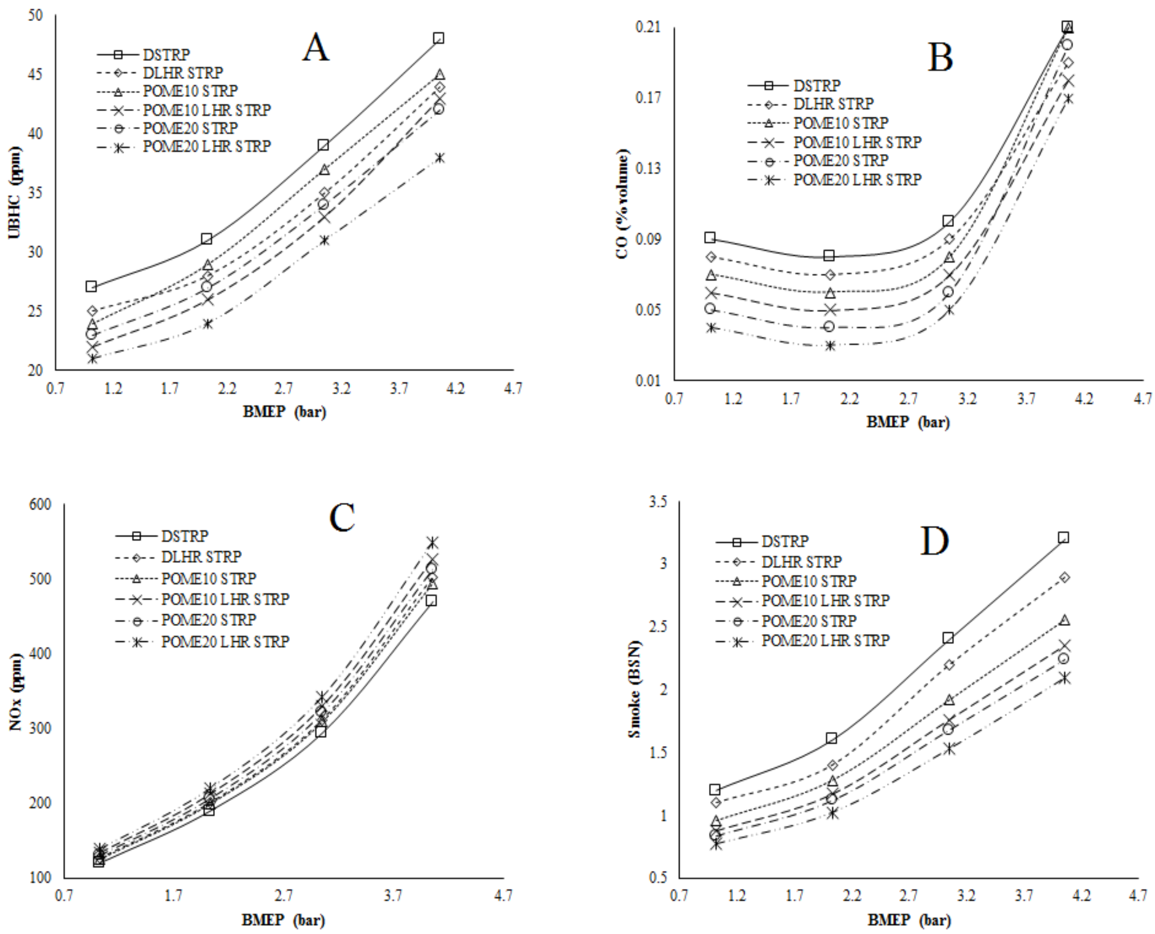

Figure 6. Variation of UBHC (A), CO (B), NO_x (C) and Smoke (D) with BMEP

The Fig (8) shows the variation of Unburned Hydrocarbons emission (UBHC) with respect to BMEP. The UBHC emissions are the result of incomplete combustion of fuel particles. The UBHC emissions are in lesser amount at low loads and keeps on increasing as the load increases. At low loads the diesel engine emits 27 ppm of UBHC with diesel and keeps on increasing up to 48 ppm at high loads. At all loads the LHR engine operating with POME20 blend exhibited lower UBHC emission than the other fuel. The LHR engine operating on POME20 blend emits a maximum 38 ppm of UBHC at high loads which is 10.5% lesser than diesel engine running with POME20 blend, 13.1% less than LHR engine running on POME10 blend and 26.31% lesser than diesel engine operating on diesel fuel. This reduction of UBHC emission in LHR engine operating with biodiesel may be due to increased oxygen content in the biodiesel and high combustion chamber temperature achieved by the ceramic coating. The Fig (9) compares the emission of Carbon Monoxide (CO) emission for different blends of fuel and LHR engine. The CO emissions occur due to the lack of availability of oxygen for completing the combustion. The CO emissions are higher at low loads and reduces with increase in loads until part load conditions. At part load the diesel engine emits 0.08% volume of CO with diesel as the fuel and it emits 0.06% and 0.04% with POME10 and POME20 blend. At full load condition, the LHR engine operating on POME20 emits 0.17% volume of CO while the LHR engine operating on diesel emits 0.19% volume of CO which is 11.76% higher than the LHR engine running on POME20. This reduction in CO emission may be attributed to the oxygen availability in the POME20 blend.The Fig (10) depicts the variation of Oxides of Nitrogen (NO_x) emission with respect to BMEP. At higher combustion temperatures the oxygen atom combines with nitrogen atom to form oxides of nitrogen. The NO_x emission is less at low load conditions and increases with increase in load. The diesel engine emits 120 ppm, 190 ppm and 470 ppm at low load, part load and full load conditions respectively. Whereas with POME10 blend it emits 126 ppm, 210 ppm and 502 ppm for low load, part load and full load conditions respectively [15-20].

The LHR engine fuelled with POME20 blend emits higher amount of 549 ppm of NO_x emission which is higher by 6.5% and 10.01% than diesel engine fuelled with POME20 and POME10 respectively. The higher NO_x emission in biodiesel fuelled LHR engine may due to the high temperature obtained by the combined effect of ceramic coating and oxygen content in the biodiesel. The amount of smoke emitted varying with BMEP is shown in Fig (11). The smoke emissions are lesser in biodiesel fuelled engine. The LHR engine operating on POME20 blend emits 2.1 BSN at full load condition which is 52.3% lower than the diesel engine operating with diesel as the fuel. Whereas the diesel engine emits 3.2 BSN and 2.2 BSN of smoke while operating on diesel and POME20 blend respectively. This reduction in smoke emission may be due to the enhanced combustion of fuel particles [7].

CONCLUSION

The effect of LHR alumina coating on piston of the Single cylinder DI compression ignition engine fuelled with blends of Pongamia oil Methyl ester were investigated and the following conclusions were drawn,

- ❖ 0.3mm Alumina coating was successfully accomplished on the piston surface through thermal detonation spray technique.
- ❖ Transesterification of Pongamia oil yielded 93% on POME and was subjected to GC/MS. Oleic acid was noticed to be present in prominent quantity along with Palmitoleic acid, Margaric acid, Arachidic acid and Palmitic acid. The physio-chemical properties of POME and its blends were found to be within standards.
- ❖ The in-cylinder pressure was found to decrease at all operating condition with increase in POME blends. The induction of LHR ceramic coated piston increased the in-cylinder pressure by 5% to 6%. The ROHR was also noticed to be higher by 4% to 5% with POME blends on LHR coated engine.
- ❖ The BTE was found to decrease by 2.5% with increase in POME concentration but positive enhancement was noticed with employment of Alumina coating. The BSEC was also found to decrease with LHR for all blends of POME.
- ❖ UBHC, CO and Smoke was found to reduce significantly with a marginal increase in NO_x for all blends of POME using LHR engine.

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