ISSN: 0975-8585

Research Journal of Pharmaceutical, Biological and Chemical Sciences

Experimental Investigation of Partially Ceramic Coated Combustion Chamber on Combustion, Performance and Emission Characteristics in a Single Cylinder Direct Injection CI Engine.

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ABSTRACT

Rapid consumption of the fossil fuel resources has driven the researchers to seek for methods to conserve energy and improve the engine's efficiency. About one third of the energy released by the diesel fuel is being absorbed by the coolant. This loss of energy can be reduced in a Low Heat Rejection (LHR) engine in which the piston crown and cylinder head is coated with ceramic materials. The present analysis aims to compare the Combustion, performance and emission characteristics of a partial LHR engine coated with alumina of 0.3mm thickness with the standard DI diesel engine equipped with the optimized Shallow Toroidal Re-entrant Geometry LHR piston. The experiments were conducted in a single cylinder DI diesel engine and the performance, emission and combustion analysis were carried out. It was noticed that there is an increase in Brake thermal efficiency, decrease in Brake specific Energy consumption and an increase in oxides of Nitrogen emission in partial LHR engine equipped with optimized Shallow Toroidal Re-entrant Geometry LHR piston when compared with baseline engine equipped with optimized Shallow Toroidal Re-entrant Geometry piston. The Shallow Toroidal Re-entrant Geometry piston was optimized as the better piston geometry based on its performance and emission characteristics when compared with Standard Toroidal Geometry piston and Hemispherical Open Geometry.

Keywords: Compression ratio, Low heat rejection, Combustion, Performance, Emission

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INTRODUCTION

The depletion of petroleum products are increasing at an alarming rate, which made the need for utilizing the fuel's energy to a maximum extent. The annual diesel consumption is found to be more than the other fossil fuel resources because of its high energy and less fuel consumption which made them to be used primarily in Automobiles and secondarily in agriculture applications. Since the vehicle population increases day by day there is a need to conserve the energy contained in the fuel. Normally the efficiency of a diesel engine lies in the range of 30% to 40%, which indicates that about 60% to 70% of the fuel energy is being wasted. This loss of heat energy is absorbed by the coolant and combustion products. Researches are being carried out to minimize the heat loss from the fuel by insulating the combustion chamber from the coolant with the help of ceramic materials. A diesel engine in which the combustion chamber parts coated with ceramic materials is known as a Low Heat Rejection (LHR) engine. The LHR engine minimizes the absorption of heat generated within the combustion chamber [6].

The LHR engine coated with partially stabilized zirconia operating with biodiesel and diesel was analysed in a 4 stroke DI diesel engine. The results showed an increase in Brake thermal efficiency, decrease in fuel consumption and an increase in NO_x emissions and particulate matters for an LHR engine running with biodiesel [11]. The cylinder head coated with $CaZrO_3$ and the piston crown with $MgZrO_3$ was tested in a six cylinder, turbocharged DI diesel engine for different speeds, loads and injection timings were analysed for performance and emission characteristics. It was concluded that BSFC reduced by 6%, NO_x levels increased by 9% for the LHR engine and the injection timing of 16 BTDC emits lesser NO_x emissions [1,2]. Different types of piston geometries were analysed in a DI diesel engine with Pongamia biodiesel blends. The results showed that the performance parameters and emission levels for a Toroidal re-entrant geometry was better than the other piston geometries [7,8]. The Toroidal re-entrant geometry showed better dynamics of the fuel mixture than the other geometries. The present research work aims to compare the combustion, performance, and emission characteristics of diesel fuel in the standard diesel engine and partial LHR engine equipped with optimized combustion geometry.

Nomenclature	
CI	Compression Ignition
DI	Direct Injection
BSEC	Brake Specific Energy Consumption
BTE	Brake Thermal Efficiency
UBHC	Unburned Hydrocarbons
CO	Carbon Monoxide
NO_x	Oxides of Nitrogen
BTDC	Before Top Dead Centre
STG	Standard Toroidal Geometry
STRG	Shallow Toroidal Re-entrant Geometry
HOG	Hemispherical Open Geometry
CAD	Crank Angle Degree
LHR	Low Heat Rejection

MATERIALS AND METHODS

Combustion chamber modification and LHR Ceramic coating

The influence of combustion chamber geometry on diesel and LHR engine were analysed. The piston was modified to Hemispherical Open Geometry (HOG) Fig 1C and Shallow Toroidal Re-entrant Geometry (STRG) Figure 1B from the Baseline Standard Toroidal Geometry (STG). Fig 1A. The 3-D modelling of the three geometries have been done using CATIA V5 software. The photographic views of the pistons are shown in Figure 1A, 1B, 1C, 1D.

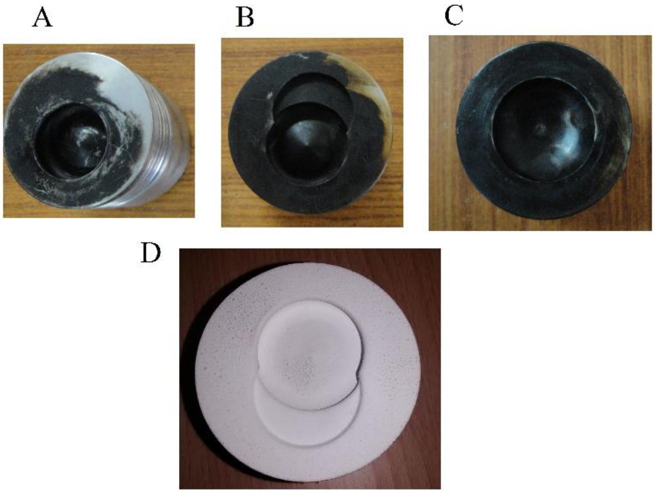

Figure 1: Pictorial view of Standard Toroidal Geometry (A), Shallow toroidal Re-entrant Geometry (B), Hemispherical Open Geometry (C) and Shallow toroidal Re-entrant Geometry-LHR piston

The compression ratios for the pistons were determined using molten wax method. The compression ratio of the STG was 18:1 whereas the compression ratio for the modified HOG and STRG were found to be 19.04:1 and 16.40:1 respectively. The piston crown has been coated with Alumina Al_2O_3 of 0.3mm thickness to convert the standard diesel engine into partial LHR engine. The piston crown is machined to reduce 0.3mm before applying the coating material so that the actual dimensions of the engine was not altered. Plasma spray coating method is used to coat the material on the piston crown [3,15].

Experimentation

Greaves model 5520 Single cylinder DI diesel engine was selected to conduct the experiments. The technical specifications of the engine has been given in Table 1. The engine is loaded with an electrical DC generator dynamometer using rheostat load bank. The emission parameters were analysed using Crypton 5 gas analyser which measures CO, CO_2 UBHC and NO_x emissions using NDIR technique and chemiluminescent technique respectively. STG, HOG and STRG were analysed for optimized performance and emission characteristics using diesel fuel. The optimal piston geometry has been taken for the application of LHR concept. The optimal piston has been coated with pure Alumina (Al_2O_3) and the coated piston is installed in the engine and the combustion, performance and emission characteristics have been analysed with diesel as the operating fuel.

Figure 2: Pictorial view of Test Engine

ISSN: 0975-8585

Table 1: Test Engine Specification

Make and Model	Greaves 5520
Engine type	Single cylinder, Four Stroke
Injection Timing	26° BTDC
Rated Power	3.73 kW @ 3000 rpm
Cylinder capacity(cc)	325
Bore (mm)	78
Stroke(mm)	68
Speed(rpm)	3000-3600
Compression ratio (STG)	18 : 1
Compression ratio (STRG)	16.4 : 1
Compression ratio (HOG)	19.04 : 1

RESULTS AND DISCUSSIONS

Variation in Combustion Parameters

The variation of in-cylinder pressure for HOG, STG, STRG and STRG LHR piston at full load condition is shown in Figure (3). It can be noticed that the in-cylinder pressure of HOG piston was 50 bar while STG and STRG piston showed 59.5 bar and 60 bar pressure respectively. The LHR alumina coated STRG piston also exhibited a significant increase in in-cylinder pressure which may be due better premixed combustion phase. The part load operation of HOG, STG, STRG and STRG LHR piston showed 46 bar, 50.5 bar, 51 bar and 52.6 bar in-cylinder pressure respectively. Since premixed combustion period is influenced by delay period, the STRG LHR piston showed a reduced delay period which enhances the in-cylinder pressure. This huge variation was mainly due to alteration in the compression ratio which resulted due to a change in the combustion chamber geometry. At low load condition, a similar trend was observed with HOG piston showing lower in-cylinder pressure than STG and STRG pistons [12-10].

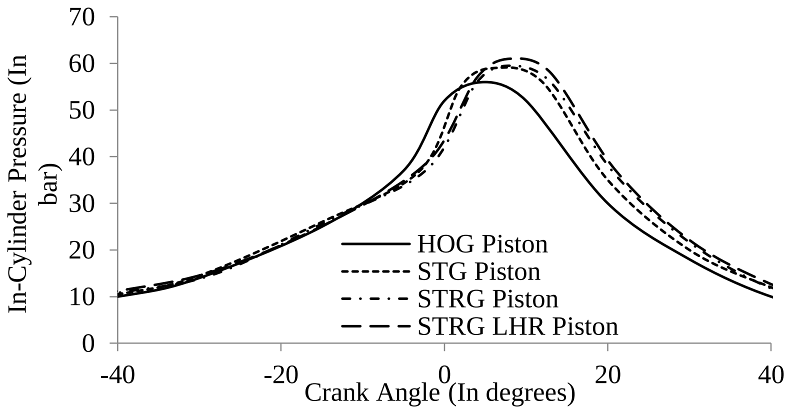

Figure 3: Variation in In-Cylinder pressure for HOG, STG, STRG and STRG LHR piston at full load

The variation of heat Release with Crank Angle for HOG, STG, STRG and STRG LHR pistons at full load operation is shown in Fig (4). It can be noticed from the Heat Release curve that enormous amount of heat generated during premixed combustion period and prolonged during diffusion combustion stage. Maximum Heat Release for all pistons was noticed between -10 CAD and 2 CAD, where the in cylinder pressure also showed a maximum value. The HOG piston showed 48 J at -8 CAD which may be due to improper atomization of air fuel mixture and reduced time lag for combustion. The STG piston and STRG piston showed a significant increase in rate of Heat release whose compression ratio were altered from 18:1 to 16.04:1 respectively. On comparison between the 3 pistons STRG piston showed enhanced combustion performance with maximum Heat Release of 56 J which may be due to increase in cylinder temperature and better atomization of air fuel mixture which resulted in enhance premixed combustion phase. The STRG LHR piston showed a better rate of

Heat Release with the alumina coating of 0.3mm which may be due to increased combustion temperature and lesser wastage of heat to surroundings [13-16].

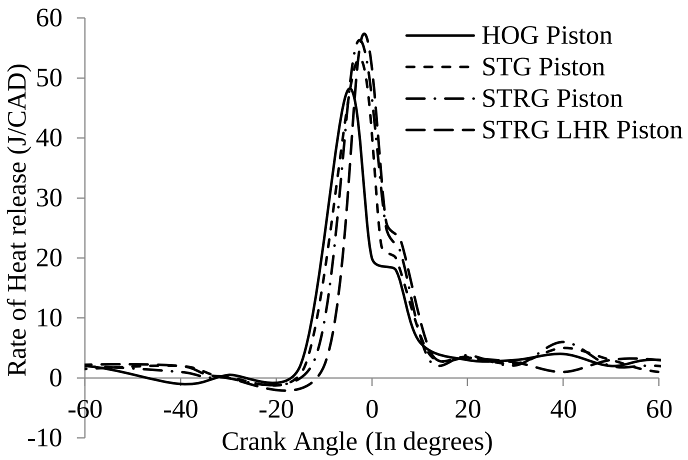

Figure 4: Variation in Heat release rate for HOG, STG, STRG and STRG LHR piston at full load

Variation in Performance and Emission parameters

The variation of Brake Specific Energy Consumption with respect to Brake Mean Effective Pressure is shown in Fig 5A. All types of pistons showed a decreasing trend with increase in load, except HOG which showed a sudden increase at full load. The STRG LHR piston consumed less energy than the other types of pistons. The STRG LHR piston consumes 11.15 MJ/kW-hr energy at full load which is lower by 2.69%, 7.18% and 35% than STRG, STG and HOG respectively. This reduction in energy consumption is may be due to the combined effect of piston geometry modification and ceramic coating which reduces the energy required for producing the same power output [4,5].

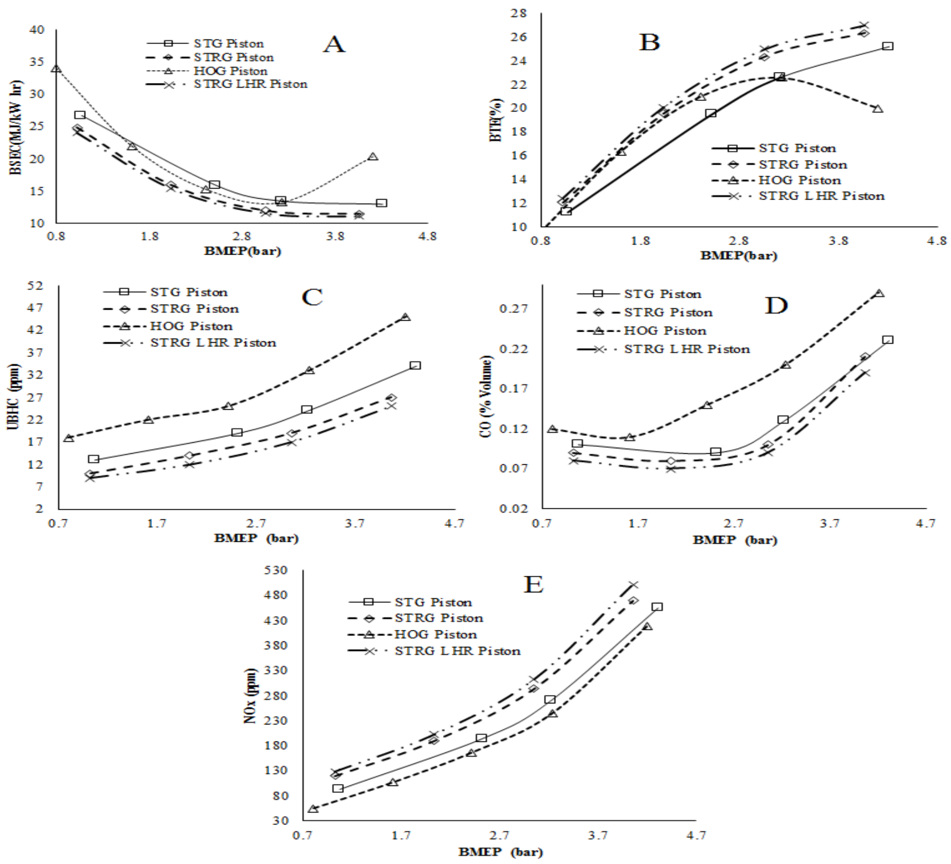

Figure 5: Variations of BSEC (A), BTE (B), UBHC (C), CO(D) and NO_x(E) with BMEP for STG, STRG, HOG and STRG LHR pistons

The variation on Brake Thermal Efficiency with respect to Brake Mean Effective Pressure for STG, STRG and HOG is shown in fig 5B. The Brake Thermal Efficiency increases with increase in load irrespective of the type of piston. The Brake Thermal Efficiency of HOG was found to be minimum at all loading conditions which may be due to improper mixing of fuel with air and high cylinder wall quenching whereas the STRG LHR piston exhibited the highest Brake Thermal Efficiency of 27.1% at full load than the other pistons. The Brake Thermal Efficiency of STRG LHR piston was found to be higher by 3.04%, 14.23%, and 45.2% than STRG STG and HOG respectively. This increase in Brake Thermal Efficiency is may be due to minimal heat loss to the coolant and the lesser consumption of fuel energy [9].

Figure 5C depicts the variation of Unburned Hydrocarbons with respect to BMEP for all types of pistons. It was noticed that the emission level of Unburned Hydrocarbons increased with increase in load for all types of pistons. The HOG emits higher amount of Unburned Hydrocarbons emissions at all types of loading conditions whereas the STRG LHR piston emits lesser Unburned Hydrocarbons at all loads. At full load the Unburned Hydrocarbons emission of STRG LHR piston was found to be lesser by 9.21%, 29.4% and 45.5% than STRG, STG and HOG respectively. This decrease in the UBHC emission in STRG LHR piston may be attributed to less amount of cylinder wall quenching also the higher combustion chamber temperatures helps in achieving the complete combustion of the fuel. The emission of CO with respect to BMEP is shown in Fig 5D. The CO emissions are found to be decreasing with increase in load upto part load condition, at part load conditions the STRG LHR piston exhibited lesser CO emission of 0.09% volume whereas the STRG, STG and HOG showed 0.1%, 0.13% and 0.15% volumes respectively. At full load the STRG LHR piston showed a minimal amount of CO emission of 0.19% volume which is lesser by 9.52%, 17.39% and 34.48% than STRG, STG and HOG respectively. This reduction in CO emission may be due to the effect of ceramic coating which aids to complete combustion. The variation of NO_x emission with respect to BMEP for all piston geometries is depicted in the Fig 5E. The NO_x emission increases with increase in load for all pistons. This is due to the high temperature at higher loads and excess availability of oxygen. The NO_x emission of ceramic coated piston is found to be higher than the other pistons at all loads. The STRG LHR piston emits a maximum of 502ppm of NO_x at full load which is higher by 6.37%, 9.36% and 16.73 % than STRG, STG and HOG respectively. This increase in NO_x emission in STRG LHR piston is due to the elevated combustion temperature and more amount of oxygen availability [17].

CONCLUSION

The variation of combustion, performance and emission characteristics on STG, HOG and STRG pistons were analyzed in detail with LHR ceramic coating on the STRG piston and the following conclusion were derived,

- The STG piston was modified to HOG and STRG piston through machining process.
- The compression ratio of STG, HOG and STRG pistons were found to be 18:1, 19.04:1 and 16.4:1 respectively through melting wax technique.
- The performance, combustion and emission analysis on all the three pistons revealed that STRG piston was optimum.
- 0.3mm alumina coating was applied on the optimum STRG piston for further analysis on low heat rejection.
- The in-cylinder pressure at full load was found to be 60 bar for STRG LHR piston whereas STG and HOG piston showed 59 bar and 50 bar respectively.
- The rate of heat release also showed significant increase upto 6% to 8% for STGR LHR piston on comparison with STG and HOG pistons due to poor premixed combustion period.
- The BSEC and BTE at full load condition were found to increase for STRG and STRG LHR piston by 4% to 6%.
- The UBHC and CO emission of HOG piston was found to increase enormously at all load while NO_x emission was increased marginally when STRG LHR piston was used.

REFERENCES

[1] Buyukkaya E, Engin T, Cerit M. Energy Conver Manag 2006; 47:1298 – 1310.
[2] Cerit M, Buyukkaya E, Engin T. App Thermal Eng 2011; 336 – 41.
[3] Hariram V, Hema Kumar M. Int J Eng Res Develop 2014; 10(11):14 – 21.

ISSN: 0975-8585

[4] Hariram V and Vagesh Shangar R. J Chem Pharm Res 2015; 7(1): 747-756.
[5] Hasimoglu C, Ciniviz M, Ozsert I, Icingur Y, Parlak A, Sahir Salman M. Renewable Energy 2008; 33:1709 – 1715.
[6] Hejwowski T, Weronski A. Vaccum 2002; 65:427 – 32.
[7] Jaichandar S, Senthil Kumar P, Annamalai K. Energy 2012; 47:388 – 94.
[8] Jaichandar S, Annamalai K, Arikaran P. Int J Autom Engm Technol 2014; 3(2):66 – 73.
[9] Khot B K, Patil P S, Hebbal O. Int J Res Eng Technol 2013; 2:120 – 124.
[10] Lakshmi S V, Reddy K V. Int J App Innov Eng Manag 2014; 3(2).
[11] Parlak A, Yasar H, Sahin B. Energy Conver Manag 2003;44(1): 163 – 75.
[12] Rajendra Prasath B, Tamil Porai P, Global J Sci Frontier Res 2010; 10(4):2 – 8.
[13] Rajendra Prasath B, Tamil Porai P, Mohammed Shabir F. Int J Thermal Sci 2010; 49:2483 – 90.
[14] Saito T, DaishoY Uchida N, Ikeya N. Effects of combustion chamber geometry on diesel combustion. Society of Automobile Engineers Paper; 1986. 861186.
[15] Santhanakrishnan S, Vijayaraj K, Arumugam N, Lakshmikanth G, Arunkumar G. Int J Res Eng Technol 2013; 2(11).
[16] Siva Kumar A, Vijaya Kumar Reddy K. Int J Innov Res Sci Eng Technol 2013; 2:2810 – 2814.
[17] Venkatraman M, Devaradjane G. J Chem Pharm Res 2014; 6(11):561 – 569.