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Control of Exhaust Emissions Using Piston Coating on Two-Stroke SI Engines with Gasoline Blends

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Abstract. An increase in fuel utilization to internal combustion engines, variation in gasoline price, reduction of the fossil fuels and natural resources, needs less carbon content in fuel to find an alternative fuel. This paper presents a comparative study of various gasoline blends in a single-cylinder two-stroke SI engine. The present experimental investigation with gasoline blends of butanol and propanol and magnesium partially stabilized zirconium (Mg-PSZ) as thermal barrier coating on piston crown of 100 μm . The samples of gasoline blends were blended with petrol in 1:4 ratios: 20 % of butanol and 80 % of gasoline; 20 % of propanol and 80 % of gasoline. In this work, the following engine characteristics of brake thermal efficiency (BTH), specific fuel consumption (SFC), HC, and CO emissions were measured for both coated and non-coated pistons. Experiments have shown that the thermal efficiency is increased by 2.2 % at P20. The specific fuel consumption is minimized by 2.2 % at P20. Exhaust emissions are minimized by 2.0 % of HC and 2.4 % of CO at B20. The results strongly indicate that the combination of thermal barrier coatings and gasoline blends can improve engine performance and reduce exhaust emissions.

Keywords: brake thermal efficiency, Mg-PSZ, exhaust emissions, gasoline blends, specific fuel consumption.

1 Introduction

Research in biofuels aims to achieve two essential goals. The first goal is to improve the engine performance and efficiency of the engine. And the second goal is the minimizing of exhaust emission gases from the engine. Several researchers have done their experimental investigations on alternative fuels in the last few decades to achieve the above goals and reduce fossil fuel dependency and harmful engine emissions. Among those, bio-alcohols such as butanol and propanol are considered very promising alternative fuels.

The available surface modification technologies will be the most crucial method to expand piston use, especially the aluminum alloy piston, for automotive. However, since the coating is primarily helpful for corrosion resistance, it should be reconsidered against high temperatures. Therefore, the application of thermal barrier coating, which was widely investigated in the 1980s, can increase thermal efficiency and reduce emissions. Most of the researchers have analyzed the thermal barrier coatings on piston crowns for internal combustion engines.

2 Literature Review

In the article [1], the authors investigated thermal barrier coatings as magnesium partially stabilized zirconium with ethanol and butanol as gasoline blends. From the experimentation, the author concluded that the engine performance parameters of SFC are 1.8 % minimized at B20 for Mg-PSZ, brake thermal efficiencies is 4.5 % maximized at B20 for Mg-PSZ, emission characteristics of HC are minimized by 2.4 % at E20, and CO is minimized by 3.7 % at E20 for Mg-PSZ coated piston is compared with the normal piston of gasoline, and gasoline blends at different concentrations.

In the article [2], the authors carried out their experimental investigations on two-stroke SI engines using a novel piston and gasoline blends as ethanol and methanol to observe the exhaust emissions and engine performance. From the experimentation results, the exhaust emissions are HC and CO is minimized by 10–15 %, and 7–12 % for ethanol-gasoline blend, the brake thermal efficiency is maximized by 1.0 %, and SFC is

minimized by 10–12 % for methanol gasoline blend for a novel piston.

Kumar et al. [3] performed experimentation on SI engines with thermal barrier coatings and gasoline blends to reduce exhaust emissions. The experimentation results have shown that the brake thermal efficiency is increased by 9.0 %, the SFC is minimized by 4.5 %, and exhaust emissions of HC and CO are minimized by 6.0 % and 5.6 %.

Nagini et al. [4] realized their investigations on four-stroke SI engines with copper as thermal barrier coat with different gasoline blends along with catalytic converters at exhaust manifold to monitor the exhaust emissions. From the investigations, the authors concluded that exhaust emissions are minimized.

Dhomne et al. [5] discussed the thermal barrier coatings for two-stroke SI engines. The author discussed different thermal barrier coating materials and their properties that affect SI engine performance, combustion, and emission characteristics. From the reviews, the authors concluded that the proper selection of material should be made. It gives a positive result.

Dudareva et al. analyzed thermal barrier coatings on aluminium alloy piston coatings is micro-arc oxidation on piston crown by using ANSYS. The MAO coating thickness of 76 and 106 μm was applied to the piston crown. The author concluded that the thickness does not significantly affect the thermal state of pistons from the analysis.

Masum et al. [7] conducted experiments on SI engines to determine the effect of ethanol on NO_x emissions. The author discussed the prospect of fuel ethanol as a gasoline substitute and comparative physicochemical properties of ethanol and gasoline. Finally, the author discussed the engine parameters and their effect on NO_x. Finally, the author concluded that the ethanol showed the effect, i.e., a lower amount of NO_x emissions were formed and improved engine performance.

Mittal et al. [8] investigated SI engines with partially coated LHR as Zirconium Dioxide by 8.0 %, by weight of Yttrium Oxide to a thickness of 0.3 mm by plasma spray method on piston crown with gasoline blend as n-butanol 10.0 % and 15.0 % by volume. The author concluded that the SFC is minimized by 1.5–0.9 %, the brake thermal efficiency is maximized by 3.2–7.4 %, and exhaust emissions are decreased due to LHR coated on the piston crown.

Krishna et al. [9] comparatively studied the performance evaluation of two-stroke copper-coated 300 μm thickness on spark-ignition engines with alcohols and catalytic converters. The authors have done investigations to find the effect of engine performance parameters and exhaust emissions. From the results, the authors concluded that the brake thermal efficiency is increased by 4 % on CCE with gasoline blends, the emissions are reduced by 20–40 %.

Parlak et al. [10] found the effect of the M15 blend on SI engine for engine performance and exhaust emissions with thermal barrier coatings. The author concluded that reducing HC and CO emissions is 32.2 % of 6.2 % and

SFC is reduced to 3.4 %, and brake thermal efficiency is increased by 8.2 %, respectively.

Kumar et al. [11] conducted experimental investigations to find the performance and emission characteristics of low heat rejection spark-ignited engines fuelled with E20. Al₂O₃ of 0.3 mm thickness applied on piston crown and cylinder head. From the results, the brake thermal efficiency is increased by 13.5 %. HC emissions are reduced to 2.3 to 17.6 %, and 3 to 16.0 % of emissions are reduced.

Magadam et al. [12] investigated the performance and emission testing of modified pistons in 2-stroke engines using refractive index material coating to improve engine efficiency and reduce emissions. The author inferred from the findings that the actual fuel consumption is reduced by 3.0 % and that thermal efficiency – by 0.9 %.

Sharma et al. [13] conducted experimentation on SI engine with thermal barrier coating by adding argon as inert gas to find the performance and emission characteristics. The author concluded that by adding inert argon gas as an intake mixture, exhaust emissions are reduced, and engine performance increases.

Most researchers have analyzed the effect of thermal barrier coatings on piston crowns for single-cylinder petrol engines with gasoline blends from the above literature review. The present experimental investigations were done on the Magnesium Partially Stabilized Zirconium (Mg-PSZ) coating on piston crown of 100 μm with gasoline blends butanol and propanol of ratio 1:4 where less experimentation will be done.

3 Research Methodology

The schematic experimental setup is shown in Figure 1.

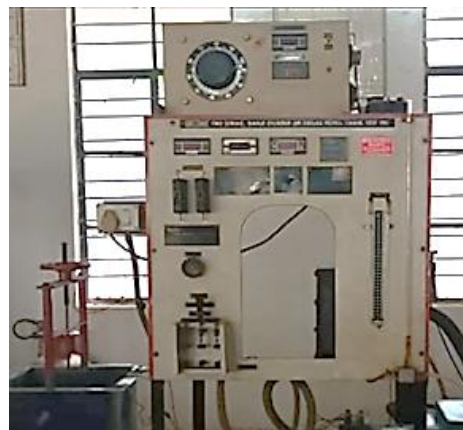


Figure 1 – Experimental setup

The experiments were conducted at five load levels at no load condition, 25 %, 50 %, 75 %, and at full load condition at a constant speed of 3000 rpm. The tests were conducted on two pistons: basic piston and Mg-PSZ coated piston shown in Figure 2 and run with gasoline blends of B20 and P20.

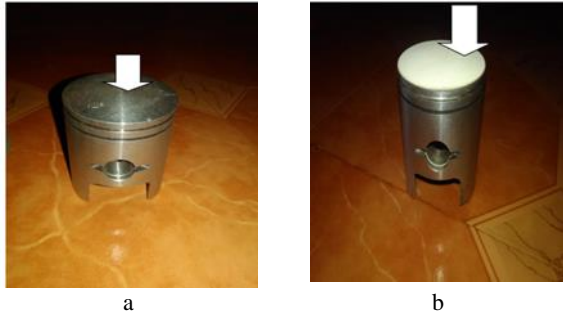


Figure 2 – Normal (a) and coated (b) pistons

The Mg-PSZ coating on piston crown of 100 μm is applied by the plasma spray method. In early attempts, used MgO to stabilize zirconia in its cubic state by adding 25 wt. % MgO. Zirconia can be fully stabilized to its cubic phase by adding 20 % yttria by weight. However, such fully stabilized zirconia coatings perform very poorly in thermal cycling tests.

Typically 7–9 wt. % yttria is used to stabilize zirconia partially, although other stabilizers have been used as well. The primary criteria for selecting a suitable stabilizer include a suitable cation radius similar to that of zirconium and a cubic crystal structure. In spite of the addition of a stabilizer to ensure the top coat's phase stability, phase changes in the topcoat might still be induced during service. The gasoline blends of butane and propane will be supplied to the engine to reduce exhaust emissions.

The above explanation shows the experimental setup, and the procedure should be as follows. When the engine starts with the standard piston and pure petrol, butanol, and propanol at no load condition, check the time taken for fuel consumption, and the current and voltage will be observed on the panel board, with gas analyzer notice the exhaust emissions. Then by applying the different loads, the same procedure will be followed. Replacing the new piston, i.e., piston coated with Mg-PSZ, and the test procedure will be repeated. A comparative result analysis will be made between the normal piston and piston coatings along with gasoline blends by noticing all the parameters.

A two-stroke air-cooled single-cylinder spark-ignition engine with an electrically loaded eddy current dynamometer is used for the investigation.

Tables 1–2 give a specification of the engine and dynamometer. Tables 3–4 present properties of Mg-PSZ and fuel, respectively.

Table 1 – Engine specification

Item	Specifications
BHP	3HP
Speed	3000 RPM
No of Cylinders	1
Bore	57mm
Stroke	57mm
Compression Ratio	7.4:1

Table 2 – Dynamo mater specification

Item	Specifications
Power	3 kW
Speed	3000 rpm
Type	Compound wound

Table 3 – Properties of Mg-PSZ

Property	Value in metric unit
Density, kg/m^3	5600
Modulus of elasticity, GPa	350
Flexural strength, MPa	545
Compressive strength, MPa	1700
Fracture toughness, $\text{MPa}\cdot\text{m}^{0.5}$	6
Hardness, HV	1100
Thermal expansion (20 °C), 1/K	$1\cdot 10^{-5}$
Thermal conductivity, $\text{W}/(\text{m}\cdot\text{K})$	2.5
Specific heat capacity, $\text{J}/(\text{kg}\cdot\text{K})$	400
Max. working temperature, °C	1000
Dielectric strength (AC), kV/mm	6

Table 4 – Properties of fuel

Parameters	Petrol	Propanol (P20)	Butanol (B20)
Density, kg/m^3	745	0.754	0.810
Flashpoint, °C	N/A	29.2	33.3
Fire point, °C	25	30.0	36.5
Calorific value, MJ/kg	43	32.4	33.3
Octane number	90	100	96

4 Results and Discussion

4.1 Specific fuel consumption

The results which are obtained from the experimental setup are discussed below. From the results, a comparative study will be taken for both pure petrol and gasoline blends with changing of the regular piston and Mg-PSZ coated piston. The comparative statements will be discussed on brake thermal efficiency, specific fuel consumption, HC, and CO. Load vs SFC is presented in Figure 3.

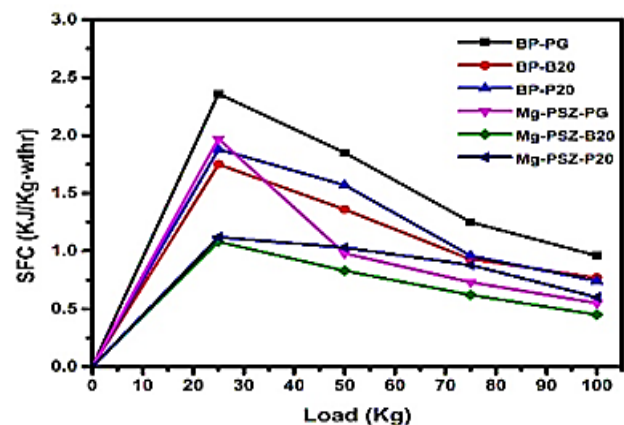


Figure 3 – Load vs SFC

Comparison of load vs SFC of both the base and the coated pistons runs at maximum speed when fuelled with gasoline blends of P20 and B20 is shown above in Figure 3. It can be observed from the results that the gasoline blends B20 and P20 with Mg-PSZ coated on piston crown reduces the SFC when compared with the uncoated piston. This may be due to the increased temperature of the piston crown, which increases the temperature of the cylinder, which causes high temperature, which contributed to higher vaporization rates of gasoline blends extracting the minimum energy out of combustion from gasoline fuels in the combustion chamber. The graph shows that for the base piston and coated piston, the SFC, for pure gasoline, is minimized by 2.74 %, minimized by 2.71 % at B20, and minimized by 2.23 % at P20.

The overall specific fuel consumption is enhanced by 2.23 % on Mg-PSZ coated piston at P20 when compared to the base piston with the blends of butanol and propanol.

4.2 Brake thermal efficiency

Load vs brake thermal efficiency (BTH) is presented in Figure 4.

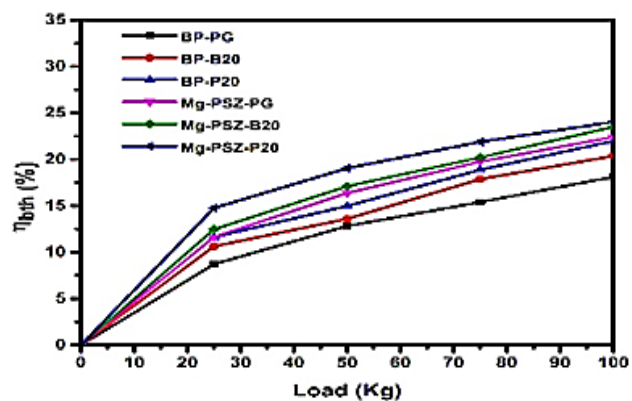


Figure 4 – Load vs BTH

Comparison of brake thermal efficiency vs a load of both the base piston and coated piston runs at maximum speed with gasoline and gasoline blends as shown in Figure 4. This may be attributed to the lower amount of energy consumption required to generate some energy with thermal barrier coatings and gasoline blends, making use of higher gas temperatures and the characteristic advantage of more oxygen in gasoline blends to improve brake thermal efficiency. The graph shows that on pure gasoline for base piston and coated piston, the efficiency is increased by 2.09 %, at B20 2.15 % of efficiency is increased, and for P20 2.23 % of efficiency is increased.

Therefore, the overall brake thermal efficiency is enhanced by 2.23 % on Mg-PSZ coated piston at P20 compared to the base piston with blends of butanol and propanol.

4.3 Hydrocarbons

Load vs hydrocarbons (HC) is presented in Figure 5.

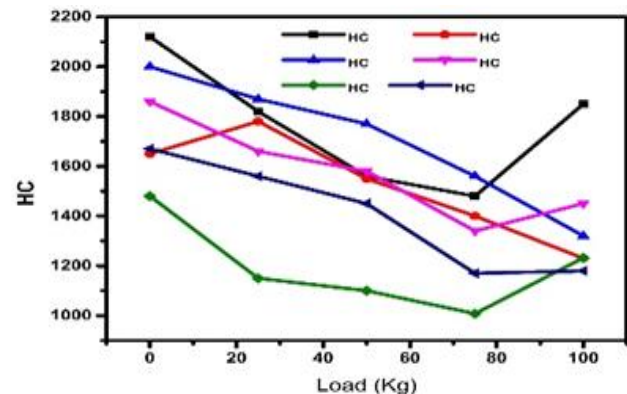


Figure 5 – Load vs HC

Comparison of HC emissions from engine exhaust concerning pure and gasoline blends for both base and coated piston runs at maximum speed as shown in Figure 5. The amount of HC emissions depends upon the engine operating conditions and fuel properties. The engine operated with B20 and P20 gasoline blends and Mg-PSZ piston coating lead to reducing HC emissions due to the sufficient temperature and oxygen presence in the combustion leading to proper combustion. From the graph at pure gasoline at base and Mg-PSZ coated piston, the HC emissions are minimized by 2.27 %, at B20 2.0 %, at P20 2.11 % of emissions are minimized.

Therefore, overall HC emissions are minimized by 2.0 % at B20 for Mg-PSZ coated piston compared with the base piston at B20 and P20.

4.4 Carbon mono oxide (CO) emissions

Comparison of CO emission from engine exhaust concerning pure gasoline and gasoline blends for both base and coated piston runs at maximum speed as shown in Figure 6.

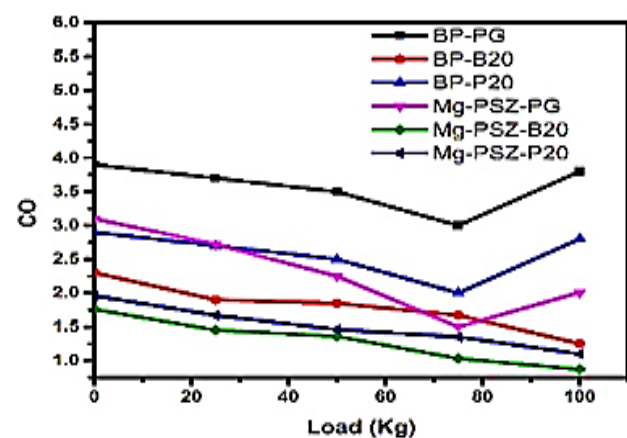


Figure 6 – Load vs CO

It can be observed from the results that the coated piston with gasoline blends reduces the CO due to the presence of oxygen in combustion plays a significant factor in CO emissions for SI engines. The addition of piston coatings and gasoline blends leads to proper combustion explained by supplying sufficient oxygen and increasing combustion temperature during the expansion stroke. From the graph, at pure gasoline for base and Mg-PSZ coated piston, the CO emissions are minimized by 3.54 %, at B20 2.4 %, and at P20 2.8 % of emissions are minimized.

Therefore, overall CO emissions are minimized by 2.4 % at B20 for Mg-PSZ coated piston compared with the base piston at B20 and P20.

5 Conclusions

The experimental setup of the work was to characterize the effect of Magnesium Partially Stabilized Zirconium (Mg-PSZ) piston coatings for different gasoline blends of propanol and butanol on engine behavior is compared with the regular piston. The Mg-PSZ piston coating shows the most effective engine performance and emission characteristics with the gasoline blends of B20 and P20.

The effect of Mg-PSZ piston coating at P20 by noticing that the minimizing of the fuel consumption is 2.23 %. The brake thermal efficiency is maximized by 2.23 % at P20 for Mg-PSZ coated piston. The emissions are minimized by 2.0 % of HC at B20 for Mg-PSZ coated piston. The 2.4 % of CO with the Mg-PSZ piston coating at B20.

These results are compared to the base piston and Mg-PSZ coated piston with P20 and B20. The emissions were minimized at B20 for Mg-PSZ coated piston. The performance characteristics are maximized at P20 for the Mg-PSZ coated piston.

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