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# Optimization Technique Approach on a Two-Stroke Engine with Coated Piston and Gasoline Blends

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## A B S T R A C T

The performance and emissions affected by the coating have been analyzed in this study. In the present experimental investigation with gasoline blends of butanol and propanol along with magnesium partially stabilized zirconium (Mg-PSZ) as thermal barrier coating on piston crown of 100 microns. The samples of gasoline blends were blended with petrol in 20:80 ratios (20% of ethanol and 80% of gasoline, 20% of butanol and 80% of gasoline). The specific standard parameters have been modified with Mg-PSZ coated petrol engine with aid of design of experiment by Taguchi with grey relational analysis optimisation method, for improving the engine performance and emission reduction. The result shows that modified Mg-PSZ coated piston at B20. Finally, the results of the experiments were compared with uncoated and coated engine and optimised parameters have been identified for Mg-PSZ coated modified piston using Taguchi grey relational method.

**Keywords:** Gasoline Blends, Taguchi Grey Relational Analysis, Engine Performance, Exhaust Emissions, Thermal Barrier Coatings

## Introduction

Biofuels are today a reality and are receiving more and more attention from society, industry and the academy. Several factors contribute to this but the most relevant and related to the uncertainty of fossil fuels price is the search for lower emissions and also for different options of energy generation. All those biofuels can be derived from renewable feedstock and not from fossil feedstock as in the case of gasoline or diesel fuels. Apart from the renewability, the advantages of biodiesels are as follows high oxygen content, higher flash point, and higher lubricity that produce complete combustion in comparison with conventional diesel fuel.[1] Alcohol is widely used as biofuel. Ethanol and methanol are the most commonly used alternative fuels in internal combustion engines. The highly boosted ethanol directly injected engine to explore the limits of down-sizing for replacing high displacement gasoline engines which represent a powerful means of reducing fuel consumption and engine-out emissions at reduced production costs.[2-4] On the application of n-butanol, the performance of an engine running on n-butanol is similar to the same engine running on gasoline. For some blends of n-butanol and gasoline, the fuel consumption is about the same or even lower than the same engine fueled with ethanol. However pure inert gases give higher specific fuel consumption about engines operating with gasoline but lower than running with inert gases.[5] This shows that the effective utilization of thermal barrier coatings and as fuel additives for investigation of methanol as 15% with additive on performance and emissions characteristics of SI engines.[6,32]

It is observed that the previous research articles concluded that in an internal combustion engine most of the heat generated during the combustion process is observed by the piston and cylinder walls. This is direct heat loss to the piston and surrounding walls. This reduces the power generated and in turn in the performance of an IC engine. To overcome this problem the thermal barrier coatings are used. By using these thermal barrier coatings on the piston crown to maintain the temperature in the combustion chamber.[7,33] The major considerations for the coating process are to be applied at a controlled thickness and several different processes are in use to achieve this control ranging from a simple coating.[8] Some of the investigations are proved that the thermal barrier coatings (MAO) on the piston crown sustain the temperature.[9-11] Simulation studies on LHR engines have been carried out on IC engines. By the researchers reported that the enhance of exhaust gas temperatures as well as the enhanced performance of an engine.[12,31] By using the finite element analysis and the simulation software ANSYS determined that improving the thermal conductivity and strength and reducing the coefficient of expansion withstand the thermal stress during the combustion process.[13] Engine modification with copper coating on crown of piston and inner side of the cylinder sides and cylinder head improves the engine performance and reduce the exhaust emissions. The copper coted engine[14-16] with methanol and ethanol as gasoline blends along with the catalytic converter.[17-20]

An optimization algorithm is a procedure that is executed iteratively by comparing various solutions till an optimum or satisfactory solution is found. From the optimization methods are approached for the experiments to response surface methodology for better performance and lower emission,[21,22] by using the Taguchi method and analysis of variance with the diesel engine.[23] The operation parameters effects are analyzed on the efficiency and emissions of the internal combustion engine via Cantera python code with optimization methods,[24] for reducing the time and cost of experiments different alternative ways such as numerical modelling, simulation, and optimization techniques can be a better option,[25] the application of Taguchi approach method for optimizing the parameters for diesel engine with Karanja methyl esters,[26,27] The catalytic coating has been analyzed with the grey Taguchi method with biodiesels on diesel engines.[28] The optimization method is carried out on IC engine with the response surface methodology with NSGA II as optimization tool no parametric regression for response surface generation.[29] The engine performance parameters and exhaust emission in compression ignition engine is fueled with biodiesel alcohol blends using the Taguchi method, multiple regression and artificial neural networks.[30]

From the above literature study, it concluded that the application of optimization techniques along with the alternative fuels and thermal barrier coatings had been done by many researchers. Form this survey with the Taguchi method with magnesium partially stabilized zirconium coating with the alternative fuel as ethanol and butanol is used for the two-stroke SI engine.

## Materials and Methodology

### Preparation of Coated Piston

**Figure 1(a).Piston before coating**

**Figure 1(b).Piston after coating**

To overcome this problem the thermal barrier coatings are used. Using the coated piston, the required temperature in the combustion chamber will be maintained. This will reduce the heat loss in the combustion chamber. The reduction in the heat loss will be used to burn the unburnt gases thereby reducing the polluted exhaust gases. The TBC consist of a bond layer and a topcoat. The bond layer is typically used to improve coating adhesion between TBC and metal substrate. The Mg-PSZ coating on piston crown of 100 microns 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 stabilised to its cubic phase by adding 20% yttria by weight. However, such fully stabilised zirconia coatings perform very poorly in thermal cycling tests. Typically, 7-9wt% yttria is used to partially stabilise zirconia, although other stabilizers have

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been used as well. The basic criteria for the selection of a suitable stabiliser include a suitable cation radius, similar to that of zirconium, and a cubic crystal structure. Despite the addition of a stabilizer to ensure phase stability of the topcoat, phase changes in the topcoat might still be induced during service. The gasoline blends of propanol, butanol and ethanol will be supplied to the engine to reduce the exhaust emissions.

Schematic setup layout of Experimental setup:

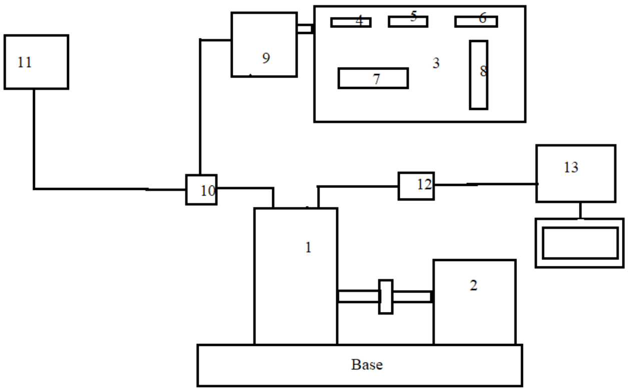


**Figure 2.Schematic setup layout of Experimental setup**

## Experimental Setup

**Figure 3.Experimental setup**

A two-stroke air-cooled single-cylinder spark-ignition engine with an electrically loaded eddy current dynamometer is used for the investigation. The base engine and generator specifications are listed below Tables 1 and 2.

**Table 1.Engine Specifications**

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

**Table 2.Generator Specifications**

| Item | Specifications |
|---|---|
| Power | 3kW |
| Speed | 3000 RPM |
| Type | Compound Wound |

When the engine starts with standard piston and pure petrol, ethanol and propanol at no load condition, check the time taken for fuel consumption, and noticing 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. By replacing the new piston, i.e., piston coated with Mg-PSZ and the test procedure will be repeated. By noticing all the parameters, a comparative result analysis will be made between the normal piston and piston coatings along with gasoline blends.

## Methodology

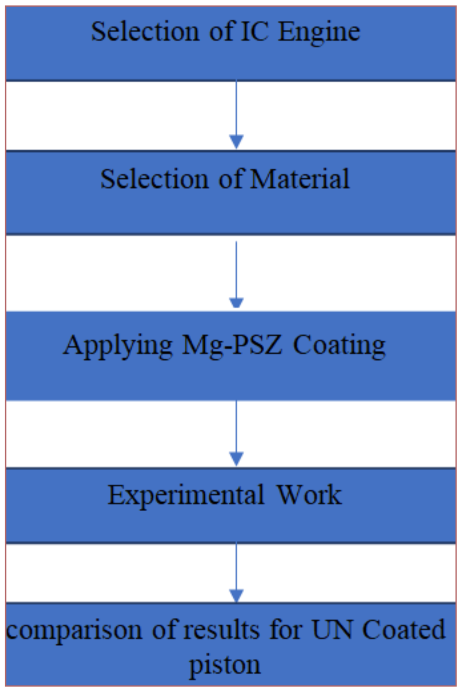


**Figure 4.Step by Step Process Involved in Experimental Work**

**Table 3.Properties of Mg-PSZ**

| Property | Value in metric unit | |
|---|---|---|
| Density | 5.6 *10³ | kg/m³ |
| Modulus of elasticity | 350 | GPa |
| Flexural strength | 545 | MPa |
| Compressive strength | 1700 | MPa |
| Fracture toughness | 6 | MPa*m½ |

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| | | |
|---|---|---|
| Hardness | 1100 | HV |
| Thermal Expansion ($20^0$) | $10*10^{-6}$ | ºC$^{-1}$ |
| Thermal conductivity | 2.5 | W/(m*K) |
| Specific heat capacity | 400 | J/(kg*K) |
| Max. working temperature | 1000 | ºC |
| Dielectric strength (AC) | 6 | KV/mm |

**Table 4.Properties of Fuel**

| S. No. | Parameters | Petrol | Ethanol (E20) | Butanol (B20) |
|---|---|---|---|---|
| 1. | Density (Kg/m$^3$) | 745 | 0.7541 | 0.810 |
| 2. | Flash point ($^0$C) | - | 29.2 | 33.3 |
| 3. | Fire point ($^0$C) | 25 | 30.0 | 36.5 |
| 4. | Calorific value (MJ/kg) | 43 | 32.43 | 33.3 |
| 5. | octane number | 90 | 100.4 | 96 |

## Results and Discussions

### Load Vs SFC

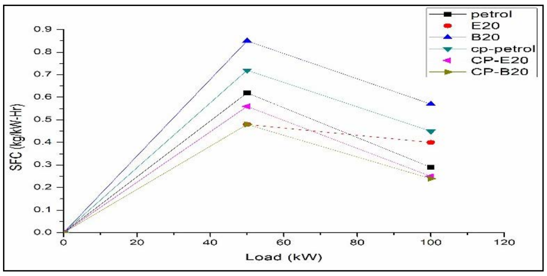


**Figure 5.Load vs SFC**

### Specific Fuel Consumption

Comparison of load Vs SFC of both the base and the coated pistons runs at maximum speed when fuelled with gasoline blends of E20 and B20 is shown in Figure 5.

It can be observed from the results that the gasoline blends B20 and P20 with Mg-PSZ coated on piston crown reduce the SFC when compared with the uncoated piston. This may be due to an increase in 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.

From the graph it is observed for the base piston and coated piston the SFC, for pure gasoline is minimised by 2.74%, 1.78% is minimised at B20, minimised by 2.71% at E20.

The overall specific fuel consumption is enhanced by 1.7% on Mg-PSZ coated piston at B20 when compared the base piston with the gasoline blends.

### Load Vs $n_{BTH}$

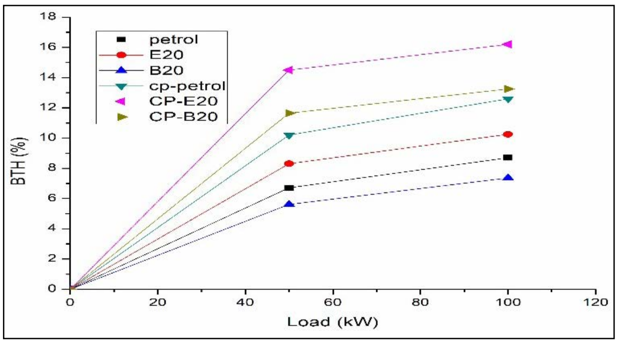


**Figure 6.Load vs BTH**

### Brake Thermal Efficiency

Comparison of brake thermal efficiency Vs load of both the base piston and coated piston runs at maximum speed with gasoline and gasoline blends as shown in Figure 6. This may be attributed to the lower amount of energy consumption required to generate some amount of energy with thermal barrier coatings and gasoline blends making use of higher gas temperatures along with the characteristic advantage of more oxygen in gasoline blends to improve brake thermal efficiency. From the graph, it is observed that on pure gasoline for base piston and coated piston the efficiency is increased by 2.09%, at E20 4.15% of efficiency is increased and for at B20 4% of efficiency is increased.

Therefore, the overall brake thermal efficiency is enhanced by 4% on Mg-PSZ coated piston at E20 when compared to the base piston with the gasoline blends.

### Load Vs HC

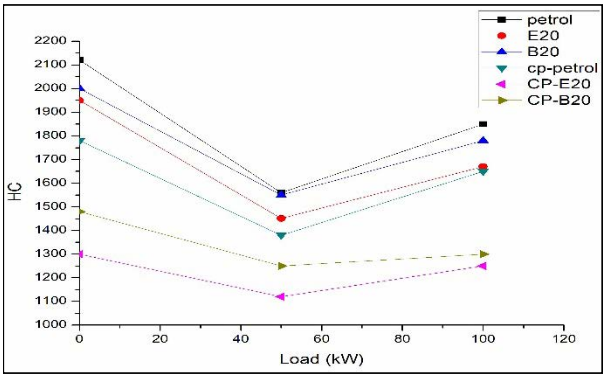


**Figure 7.Load vs HC**

### Hydrocarbons

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 7. The amount of HC emissions depends upon the engine operating conditions and fuel properties. The engine operated with E20, and B20 gasoline blends and Mg-PSZ piston coating leads to the reduction of HC emissions due

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to the sufficient temperature and oxygen presence in the combustion leads to proper combustion. From the graph at pure gasoline at base and Mg-PSZ coated piston, the HC emissions are minimised by 2.27%, at E20 2.0%, at B20 2.38% of emissions are minimised.

Therefore, overall HC emissions are minimised by 2.0% at E20 for Mg-PSZ coated piston when compared with the base piston with gasoline blends.

### Load Vs CO

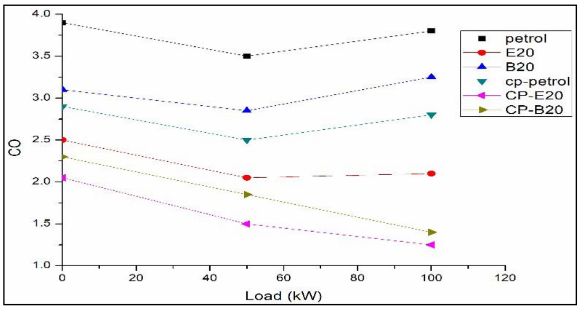


**Figure 8.Load vs CO**

### Carbon Mono Oxide

Comparison of CO emission from engine exhaust concerning pure gasoline and gasoline blends for both base and coated piton runs at maximum speed as shown in Figure 8. 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 major factor in CO emissions for SI engines. The addition of piston coatings and gasoline blends leads to proper combustion explained by supplying of sufficient oxygen and increase in combustion temperature during expansion stroke. From the graph, at pure gasoline for base and Mg-PSZ coated piston the CO emissions are minimised by 3.54%, at E20 2.4% and at B20 3.65% of emissions are minimised.

Therefore, overall CO emissions are minimised by 2.4% at E20 for Mg-PSZ coated piston when compared with the base piston with gasoline blends.

### Taguchi Method

Taguchi with grey relational analysis is the most suitable technique for multi-performance characteristics with minimum experimental work. In the present work, the Taguchi technique with the grey relational analysis method is used for finding the optimum engine parameters of the coated piston. To find the optimum solution to a problem with a minimum number of trials, the Taguchi technique is the most suitable and preferable method. In the present study two factors and three levels, L9 orthogonal array is used. The identified parameters should be in three levels such as smallest, medium, and highest levels.

In the present investigation, two factors and three levels are used. Experiments are conducted considering two input parameters fuel (%) and load (kg). overall, nine experiments are carried out.

**Table 5.Input Parameters**

| S. No. | Factors | Level-1 | Level-2 | Level-3 |
|---|---|---|---|---|
| 1. | Fuel | Petrol | E20 | B20 |
| 2. | Load | 0 | 50 | 100 |

**Table 6.Design of Experiments**

| Exp. No. | Fuel type | Load (%) |
|---|---|---|
| 1 | Petrol | 0 |
| 2 | Petrol | 50 |
| 3 | Petrol | 100 |
| 4 | E20 | 0 |
| 5 | E20 | 50 |
| 6 | E20 | 100 |
| 7 | B20 | 0 |
| 8 | B20 | 50 |
| 9 | B20 | 100 |

$$S/N\ ratio = -\log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) \quad (1)$$

The' larger is better' criteria are selected and the equation is used to determine the S/ N ratio for the beak thermal efficiency to be improved.

$$S/N ratio = -\log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right) \quad (2)$$

Where **'i'** is a whole set of experiments,**'yi'** is the final result of the experiments.

### Grey Relational Method

The inquiry aims to refine four reaction parameters for the coated piston of an IC engine, two of which are efficiency parameters and the other two are emission parameters. In this case, a higher ratio is favoured for engine output and a lower ratio for emission. As a result, Taguchi is unsuitable for multi-response optimization problems. Taguchi with grey relational analysis is used in this investigation to find the best solution to this case.

The first step in using grey relational analysis is to normalize experimental findings. The grey relational coefficients are determined in the second step after normalization. In the third stage, the total grey relational grade for each chosen answer is determined by integrating the grey relational co-efficient. Finally, the grey relational grade is used to evaluate the multiple answers.

The parameters and their levels are as follows:

Two variables and three layers are employed in this study.

Experiments were carried out with two input criteria in mind: load and fuel ratio. Overall, tests were conducted.

$$Y_{ij} = \frac{(\max(Z_{ij}) - (Z_{ij}))}{\max(Z_{ij}) - \min(Z_{ij})} \quad (3)$$

The selected criteria are better in the case of SFC and Break thermal efficiency so the equation is better:

$$Y_{ij} = \frac{(Z_{ij} - \min(Z_{ij}))}{\max(Z_{ij}) - \min(Z_{ij})} \quad (4)$$

Where Zij is the value from the experiment results, min (Zij) is the experiment's minimum value. Likewise, the cumulative data obtained from the configuration of L9 Taguchi is max (Zij). The estimation of the normalized data using the following equation:

$$GRC_{ij} = \frac{(\delta_{\min} - \gamma\delta_{\max})}{(\delta_{ij} - \gamma\delta_{\max})} \quad (5)$$

The higher grey relational grade implies the ultimate combination of eminence characteristics of tensile strength. The GRG grade is determined using the equation below.

$$GRC_i = \frac{1}{n} \varepsilon GRC_{ij} \quad (6)$$

**Table 7.Performance and Emission Results**

| Exp. No | Fuel type | Load (%) | SFC (kg/kW-hr) | BTH (%) | HC | CO |
|---|---|---|---|---|---|---|
| 1 | Petrol | 0 | 0 | 0 | 2120 | 3.9 |
| 2 | Petrol | 50 | 0.62 | 14.82 | 1560 | 3.5 |
| 3 | Petrol | 100 | 0.29 | 28.12 | 1850 | 3.8 |
| 4 | E20 | 0 | 0 | 0 | 2000 | 3.1 |
| 5 | E20 | 50 | 0.85 | 10.79 | 1550 | 2.25 |
| 6 | E20 | 100 | 0.57 | 27.36 | 1780 | 2.01 |
| 7 | B20 | 0 | 0 | 0 | 1950 | 2.5 |
| 8 | B20 | 50 | 0.8 | 16.3 | 1415 | 2.05 |
| 9 | B20 | 100 | 0.4 | 27.6 | 1600 | 2.1 |

**Table 8.Normalization values for Performance and Emission Results**

| Fuel | Load | SFC (Kg/kW-Hr) | BTH (%) | HC | CO | SFC (Kg/kW-Hr) | BTH (%) | HC | CO |
|---|---|---|---|---|---|---|---|---|---|
| P | 0 | 0 | 0 | 2120 | 3.9 | 0 | 0 | 1 | 1 |
| P | 50 | 0.62 | 14.82 | 1560 | 3.5 | 0.729411765 | 0.527027 | 0.16293 | 0.78836 |
| P | 100 | 0.29 | 28.12 | 1850 | 3.8 | 0.341176471 | 1 | 0.596413 | 0.94709 |
| E20 | 0 | 0 | 0 | 2000 | 3.1 | 0 | 0 | 0.820628 | 0.57672 |
| E20 | 50 | 0.85 | 10.79 | 1550 | 2.25 | 1 | 0.383713 | 0.147982 | 0.126984 |
| E20 | 100 | 0.57 | 27.36 | 1780 | 2.01 | 0.670588235 | 0.972973 | 0.491779 | 0 |
| B20 | 0 | 0 | 0 | 1950 | 2.5 | 0 | 0 | 0.745889 | 0.259259 |
| B20 | 50 | 0.48 | 16.3 | 1451 | 2.05 | 0.564705882 | 0.579659 | 0 | 0.021164 |
| B20 | 100 | 0.4 | 27.6 | 1600 | 2.1 | 0.470588235 | 0.981508 | 0.22272 | 0.047619 |

**Table 9.Performance and Emission Results GRG Rank List**

| | | | | | | | | | | Gray Grade | Rank |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Fuel | Load | ΔSFC | ΔBTH | ΔHC | ΔCO | ξ1SFC | ξ2BTH | ξ3HC | ξ4CO | Avg. | |
| P | 0 | 0 | 0 | 2119 | 2.9 | 1 | 1 | 0.789838 | 0.795402 | 0.89631 | 3 |
| P | 50 | 0.109412 | 14.29297 | 1559.837 | 2.71164 | 0.406699 | 0.486842 | 0.958449 | 0.831403 | 0.670848 | 7 |
| P | 100 | 0.051176 | 27.12 | 1849.404 | 2.85291 | 0.594406 | 0.333333 | 0.86304 | 0.804107 | 0.648721 | 9 |
| E20 | 0 | 0 | 0 | 1999.179 | 2.52328 | 1 | 1 | 0.820779 | 0.870817 | 0.922899 | 2 |
| E20 | 50 | 0.15 | 10.40629 | 1549.852 | 2.123016 | 0.333333 | 0.565795 | 0.962116 | 0.96837 | 0.707403 | 5 |
| E20 | 100 | 0.100588 | 26.38703 | 1779.508 | 2.01 | 0.427136 | 0.33945 | 0.884288 | 1 | 0.662718 | 8 |
| B20 | 0 | 0 | 0 | 1949.254 | 2.240741 | 1 | 1 | 0.834399 | 0.937481 | 0.94297 | 1 |
| B20 | 50 | 0.084706 | 15.72034 | 1451 | 2.028836 | 0.469613 | 0.463109 | 1 | 0.994586 | 0.731827 | 4 |
| B20 | 100 | 0.070588 | 26.61849 | 1599.777 | 2.052381 | 0.515152 | 0.337494 | 0.944053 | 0.987899 | 0.69615 | 6 |

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**Table 10.GRG Performance and Emission Result**

| Level | Fuel | Load |
|---|---|---|
| 1 | 0.7386 | 0.9207 |
| 2 | 0.7643 | 0.7034 |
| 3 | 0.7903 | 0.6692 |
| Delta | 0.0517 | 0.2515 |
| Rank | 2 | 1 |

Table 10, displays the obtained grey relational grade, where a higher grey relational grade is ranked higher. The higher grey relational grade obtained is very similar to the optimal approach. Since the experimental strategy is orthogonal, the outcomes of each grey relational grade parameter are divided into levels. The mean of the grey relational grade for the different levels 1,2,3 is determined for fuel parameters by averaging the grey relational grade for the experiments. As a result, B20 fuel at 50% load is the best parameter for the catalytic coated piston-type petrol engine.

**Table 11.ANNOVA of GRG**

| Source | DF | Seq SS | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|---|
| Fuel | 2 | 0.004008 | 0.004008 | 0.002004 | 0.59 | 0.588 |
| Load | 1 | 0.094901 | 0.094901 | 0.094901 | 28.01 | 0.003 |
| Error | 5 | 0.016941 | 0.016941 | 0.003388 | | |
| Total | 8 | 0.11585 | | | | |

**Table 12.R-Sq Value**

| Model summary | | |
|---|---|---|
| S | R- Sq | R-Sq (adj) |
| 0.058209 | 85.38% | 76.60% |

## GRA ANNOVA Analysis

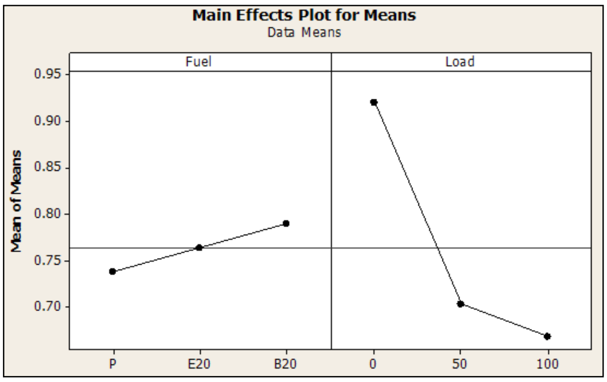


**Figure 9.GRA ANNOVA Analysis**

As a result of the ANOVA of GRG study, the second-factor load has the highest mean square value of 0.003388 and is thus defined as a significant factor that contributes to and influences the efficiency and emission characteristics of a catalytic coated IC engine. Figure 9, represents the ANOVA mean impact map and residual plots.

## Conclusion

Taguchi with the GRA technique has been very efficiently used in the optimization of the performance and emission characteristics of an Mg-PSZ coated piston type engine. The two parameters that improve the performance and reduce emission. Experiments were conducted based on the L9 orthogonal array and the engine parameters are optimized through the Taguchi-GRA experimental design.

In the present investigation, Taguchi-GRA experimental design method is used to convert the multi-response optimization problem into a single response problem. Based on the GRG result B20 fuel at 0% load is identified as an optimum parameter for Mg-PSZ coated piston.

The response such as BTH, SFC, HC CO has been determined for the coated and uncoated piston. The BTH of the Mg-PSZ coated engine has marginally improved by 2.23%, the SFC is minimized by 2.2% and the emissions of HC and CO are significantly decreased by 2.0% and 2.4% at B20 respectively. This reveals that complete combustion takes place inside the combustion chamber due to piston coating on Mg-PSZ material. Instead of a petrol fuel operated engine, Butanol(B20) fueled operated coated engine gives better results hence B20 can be used as an alternative fuel for controlling emissions.

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