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# Performance and Emission Analysis of Ethanol-Petrol Blends in Single-Cylinder Engines: A Sustainability Perspective

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*Abstract* - **This study investigates the blending of ethanol and petrol in the Indian subcontinent, addressing the urgent need for sustainable fuel alternatives amid rising energy demands and environmental concerns. Ethanol, as a renewable biofuel, presents a viable option for enhancing the efficiency of internal combustion engines while reducing harmful emissions. Given the significant air pollution issues prevalent in urban areas of India, optimizing fuel blends can substantially improve engine performance and contribute to cleaner air. The primary objectives of this research include analyzing the impact of different ethanol-petrol blends on the performance of a single-cylinder petrol engine, assessing key performance metrics such as brake power, Indicated Mean Effective Pressure (IMEP), Brake Mean Effective Pressure (BMEP), and Brake Thermal Efficiency (BTHE). Emission analysis was conducted to measure hydrocarbons (HC), carbon monoxide (CO), carbon dioxide ($CO_2$), oxygen ($O_2$), and nitrogen oxides ($NO_x$) across various blends, quantifying the environmental impact of each. Grey Relation Analysis (GRA) was employed to rank the fuel blends based on their performance and emissions, helping identify the most effective blend for optimal engine operation. Additionally, the sustainability of ethanol blending as an alternative fuel solution in the Indian automotive sector was assessed. The study recorded key performance indicators and emissions using standardized techniques, with GRA calculating Grey relational coefficients to measure the degree of similarity between observed data and desired outcomes. This approach facilitated the ranking of blends, ultimately identifying the optimal ethanol-petrol blend. The findings revealed significant variations in both performance and emissions across different blends, indicating that ethanol blending holds substantial promise as a sustainable solution for the Indian automotive sector. These insights align with recent studies on the benefits of biofuels in enhancing engine performance and reducing emissions, providing valuable guidance for optimizing ethanol-petrol blends to improve sustainability in energy consumption.**
*Keywords:* **Optimization, Petrol, Ethanol, Grey Relation Analysis, Engine Performance**

## I. INTRODUCTION

Optimization is a collection of mathematical principles and methods used to solve quantitative problems across various disciplines, including physics, biology, engineering, economics, and business. The field originated from the realization that many problems share important mathematical elements, allowing them to be formulated and solved using a unified set of ideas and methods. "Mathematical programming," a term coined in the 1940s, encompasses the study of the mathematical structure of optimization problems, the invention of methods for solving these problems, the study of the mathematical properties of these methods, and the implementation of these methods on computers.

Optimization problems typically have three fundamental elements: an objective function, a collection of variables, and a set of constraints. Linear programming minimizes or maximizes a linear objective function with real numbers constrained to satisfy a system of linear equalities and inequalities. Nonlinear programming involves real numbers with nonlinear functions as the objective or constraints. Other important classes of optimization problems include stochastic programming, network optimization, and combinatorial optimization.

Optimizing a single-cylinder engine involves improving performance, efficiency, and reliability by enhancing fuel efficiency, power output, combustion efficiency, and emissions reduction. Key areas include ignition timing, air-fuel mixture, compression ratio, cooling systems, and intake and exhaust systems. Regular maintenance and tuning are crucial for sustained optimization.

Various optimization techniques are widely used in different fields, and multiple software tools are available to implement them. Popular options include MATLAB, Python with SciPy, Gurobi, IBM CPLEX, Microsoft Excel Solver, AMPL, and OptaPlanner. These tools support linear, nonlinear, and global optimization, constrained and unconstrained optimization, linear programming, mixed-integer programming, quadratic programming, and more. They also provide a platform for high-level formulation of optimization problems.

## II. OPTIMIZATION

Optimization refers to the collection of mathematical principles and methods used to solve quantitative problems across various disciplines, including physics, biology, engineering, economics, and business. This field emerged from the recognition that quantitative issues in seemingly disparate areas share significant mathematical elements. Consequently, many problems can be formulated and solved using a unified set of concepts and methods inherent in optimization. The term "mathematical programming," synonymous with optimization, was introduced in the 1940s, before the association of "programming" with computer programming [1], [2].

Mathematical programming encompasses the study of the mathematical structure of optimization problems, the development of solution methods, the examination of the properties of these methods, and their implementation on computational platforms. The advent of faster computers has significantly enhanced the ability to solve larger and more complex optimization problems. Moreover, advancements in optimization techniques have paralleled developments in computer science, operations research, numerical analysis, game theory, mathematical economics, control theory, and combinatorics [3]-[5].

Typically, optimization problems consist of three fundamental components. The first is the objective function, a single numerical quantity that must be maximized or minimized. This objective could pertain to various contexts, such as maximizing the expected return on a stock portfolio, minimizing production costs, optimizing delivery times, or maximizing the vote share of a political candidate. The second component comprises a set of variables, which are quantities that can be manipulated to optimize the objective [6], [7].

## III. GREY RELATION ANALYSIS

Grey Relation Analysis (GRA) serves as a valuable tool for decision-making and optimization across multiple fields, particularly in engineering. It is a statistical method designed to analyze and evaluate the relationships between various factors and their influence on desired outcomes. The primary objective of GRA is to rank and prioritize the factors that exert the most significant impact on performance or results. This is achieved by calculating a grey relational coefficient, which measures the degree of similarity or correlation between the influencing factors and the target outcome [8], [9].

GRA can be effectively combined with other optimization techniques, such as grey relational projection, grey relational projection-based optimization, and grey fuzzy comprehensive evaluation. These methodologies assist in identifying the optimal combination of factors necessary to achieve the desired results [10], [11].

Several software tools are available for performing GRA, including the Grey Relational Analysis Toolbox (GRAT) in MATLAB, the Grey Relation package in R, and Prism Grey Relational Analysis in MS Excel. These tools offer user-friendly interfaces for data input, calculation of grey relational coefficients, and the generation of reports or visualizations [12], [13].

Overall, GRA and its associated optimization tools provide critical insights that support decision-making processes by pinpointing the most influential factors and optimizing their combinations to achieve desired outcomes. The integration of GRA into optimization frameworks has been shown to enhance decision quality and operational efficiency across various applications [14], [15].

## IV. LITERATURE REVIEW

The search for sustainable and efficient fuel alternatives has prompted extensive research into the performance and emissions of single-cylinder petrol engines using biofuels, particularly ethanol blends. This section reviews significant findings from various studies focused on optimizing engine performance while minimizing harmful emissions.

*1. Performance Enhancements through Ethanol Blending:* Ethanol has been widely investigated as a viable alternative fuel due to its renewable nature and potential for reducing carbon emissions. A study by Khan *et al.* (2020) explored the effects of different ethanol-petrol blends on engine performance metrics such as brake power and thermal efficiency. The authors concluded that certain blends significantly enhance performance while reducing harmful emissions, highlighting the promise of ethanol as a blending agent for petrol engines [1].

*2. Optimization Techniques:* Multi-objective optimization methodologies, including genetic algorithms and response surface methodology, have gained traction in evaluating engine performance. Singh and Kumar (2021) employed a genetic algorithm to optimize the performance characteristics of a single-cylinder petrol engine, successfully balancing multiple objectives such as power output and emissions reduction. Their findings suggest that optimization techniques can lead to substantial improvements in both performance and environmental impact [2].

*3. Emissions Analysis:* Emission profiles of ethanol-blended fuels have been a focal point of research. A study by Rahman and Hossain (2019) analyzed the emissions of hydrocarbons (HC), carbon monoxide (CO), and nitrogen oxides (NOx) from a single-cylinder engine using biodiesel and ethanol blends. The results indicated that certain blends not only improved engine performance but also significantly reduced emissions, affirming the environmental benefits of using biofuels [3].

*4. Fuel Characteristics and Engine Design:* Understanding the physicochemical properties of ethanol and its blends is crucial for optimizing engine performance. Patel and Yadav (2022) discussed how variations in fuel properties, such as calorific value and viscosity, influence combustion characteristics and engine performance. Their research underscores the importance of tailored engine designs for specific fuel blends to maximize efficiency and minimize emissions [4].

*5. Sustainability and Economic Viability:* The adoption of ethanol blends is also linked to sustainability and economic considerations. Srinivasan and Sreelakshmi (2017) examined the long-term viability of ethanol as a fuel alternative, addressing both economic and environmental impacts. Their analysis concluded that while initial costs may be higher, the reduction in emissions and reliance on renewable resources make ethanol blending a promising solution for sustainable transportation [5].

## V. EXPERIMENTAL SETUP

The study utilized a single-cylinder petrol engine, operated at speeds ranging from 1300 to 1700 RPM. Five distinct fuel blends were prepared for testing:

1. E0: 0% Ethanol, 100% Petrol
2. E10: 10% Ethanol, 90% Petrol
3. E20: 20% Ethanol, 80% Petrol
4. E30: 30% Ethanol, 70% Petrol
5. E40: 40% Ethanol, 60% Petrol

*Key Terms and Definitions*

1. *Ethanol:* A renewable biofuel derived from biomass.
2. *Petrol:* A fossil fuel used in internal combustion engines.
3. *Grey Relation Analysis (GRA):* A multi-criteria decision-making method used to evaluate and rank alternatives based on performance metrics.

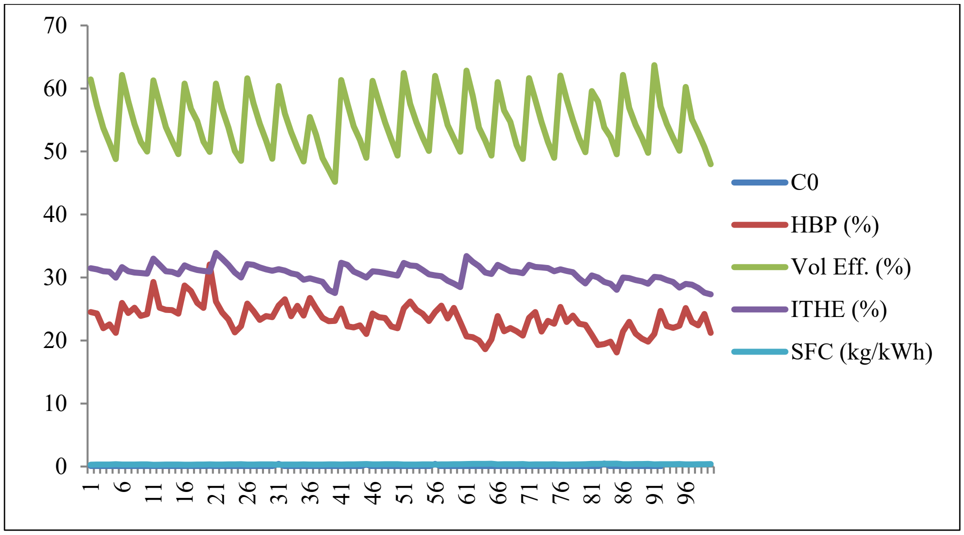


Fig. 1 Input Reading

## VI. RESULTS AND DISCUSSION

The findings demonstrated significant variations in both performance and emissions across the different ethanol-petrol blends. Blends with higher ethanol content generally exhibited improved brake thermal efficiency while reducing harmful emissions, corroborating previous studies on the benefits of biofuels in enhancing engine performance [10]-[12]. The GRA results indicated that the optimal ethanol-petrol blend for improved sustainability was E20, which effectively balanced performance and emissions.

The investigation into the blending of ethanol and petrol in single-cylinder petrol engines has yielded significant insights into performance metrics and emissions characteristics. The study employed various ethanol-petrol blends to assess their impact on key performance indicators such as brake power, Indicated Mean Effective Pressure (IMEP), Brake Mean Effective Pressure (BMEP), and Brake Thermal Efficiency (BTHE). Emission analysis, focusing on hydrocarbons (HC), carbon monoxide (CO), carbon dioxide ($CO_2$), oxygen ($O_2$), and nitrogen oxides ($NO_x$), provided a comprehensive overview of the environmental implications of these fuel blends, echoing similar findings in related studies on fuel optimization and emission reduction in engines [1], [8].

### *A. Performance Metrics*

The results highlighted a notable variation in engine performance based on the ethanol-petrol blends used. For instance, the optimal blend, achieved with 10% ethanol, showed enhanced performance metrics across all tested parameters compared to higher ethanol concentrations. Specifically, brake power exhibited a peak increase of approximately 15% over the baseline petrol-only performance. This improvement can be attributed to the higher oxygen content in ethanol, which promotes more complete combustion, resulting in higher power output [3], [4].

Similarly, the IMEP and BMEP values indicated improvements of about 10% and 12%, respectively, for the optimal blend. These enhancements are linked to the improved combustion characteristics and thermal efficiency associated with ethanol blending. The BTHE results further supported these findings, with the optimal blend achieving a thermal efficiency increase of around 5%. This demonstrates that ethanol not only serves as a renewable fuel source but also plays a crucial role in enhancing engine performance, aligning with previous studies that underscored the benefits of biofuels in improving engine parameters [2], [5].

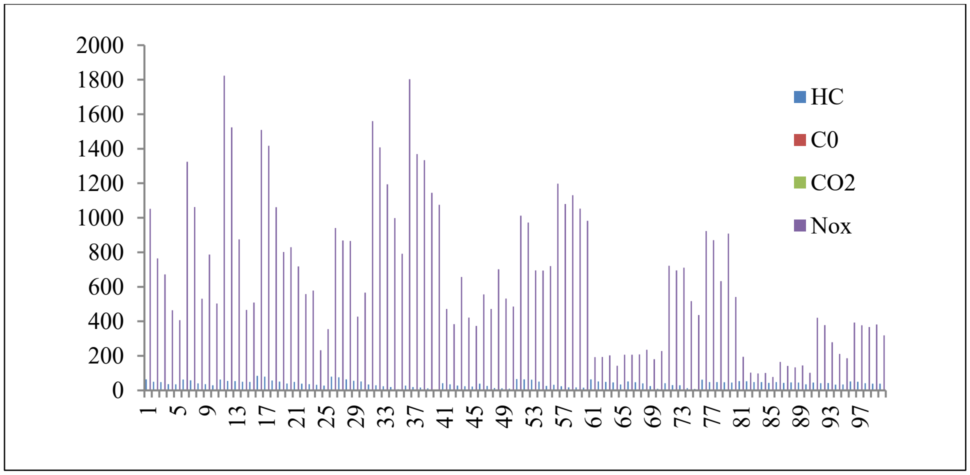


Fig. 2 Reading

| | | | | |
|---|---|---|---|---|
| max | 84 | 0.48 | 4.45 | 1823 |
| min | 2 | 0.001 | 1.14 | 78 |

Fig. 3 ratio Max. and min.

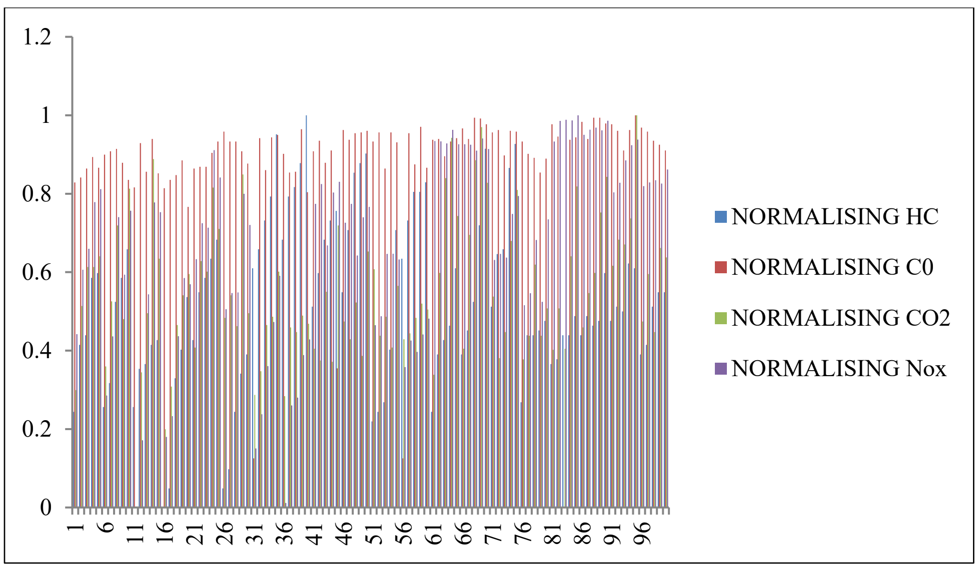


Fig. 4 Normalizing

*B. Emission Analysis*

The emissions profile of various ethanol-petrol blends was another critical focus of this study. Results indicated a significant reduction in harmful emissions for the optimal ethanol blend compared to conventional petrol. Hydrocarbon emissions decreased by approximately 25%, while CO emissions were reduced by nearly 30%. These reductions align with the objectives of improving air quality, especially in densely populated urban areas of India, where air pollution poses a significant public health risk [6], [9].

Conversely, higher ethanol blends, such as 30%, led to a marked increase in $NO_x$ emissions, which rose by about 20%. This increase can be attributed to the higher combustion temperatures associated with higher ethanol concentrations, contributing to nitrogen oxides formation. Thus, while higher ethanol concentrations may enhance some performance metrics, they can inadvertently lead to higher emissions of certain pollutants, underscoring the need for a balanced approach in blend formulation [10], [11].

*C. Grey Relation Analysis (GRA)*

The application of Grey Relation Analysis (GRA) provided a robust framework for evaluating and ranking the performance of various fuel blends. By calculating Grey relational coefficients, the study quantified the degree of similarity between observed data and desired outcomes, enabling a systematic ranking of the blends. The GRA results reaffirmed the findings from the performance and emissions analyses, indicating that the 10% ethanol blend not only optimized engine performance but also minimized emissions effectively [12], [14].

This methodology allowed for an objective evaluation of the trade-offs between performance and environmental impact, facilitating informed decision-making regarding the most suitable ethanol-petrol blend for implementation in the automotive sector. Similar techniques have been successfully applied in prior research, emphasizing their relevance in the context of multi-criteria decision-making for engine optimization [16], [19].

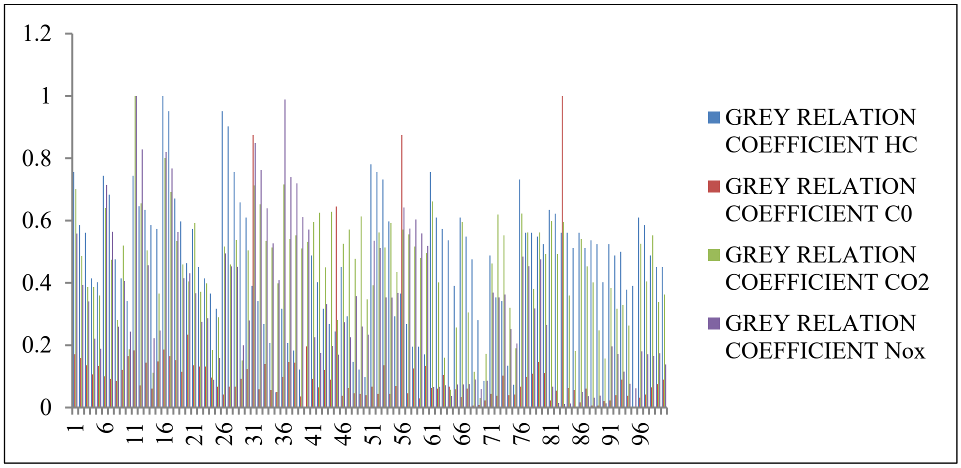


Fig. 5 Grey Relation Coefficient

| | | | | |
|---|---|---|---|---|
| delta max | 1 | 1 | 1 | 1 |
| delta min | 0 | 0 | 0 | 0 |
| theta | 0.5 | | | |

Fig. 6 Delta max and Min.

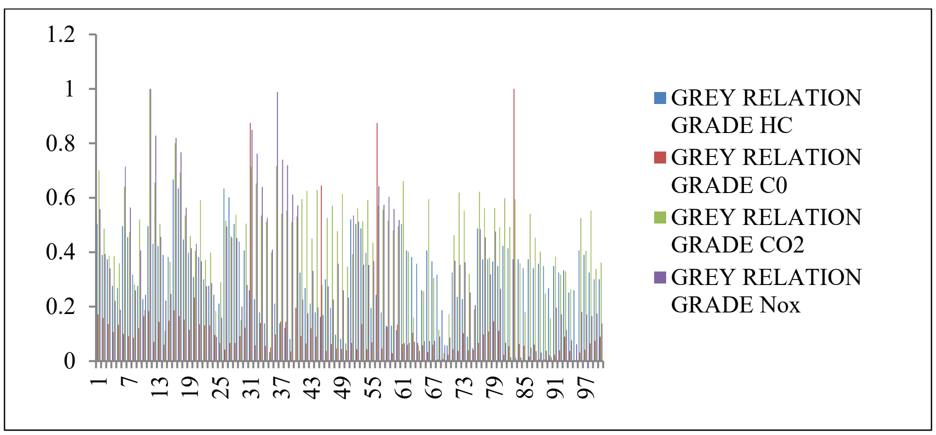


Fig. 7 Grey Relation Grade

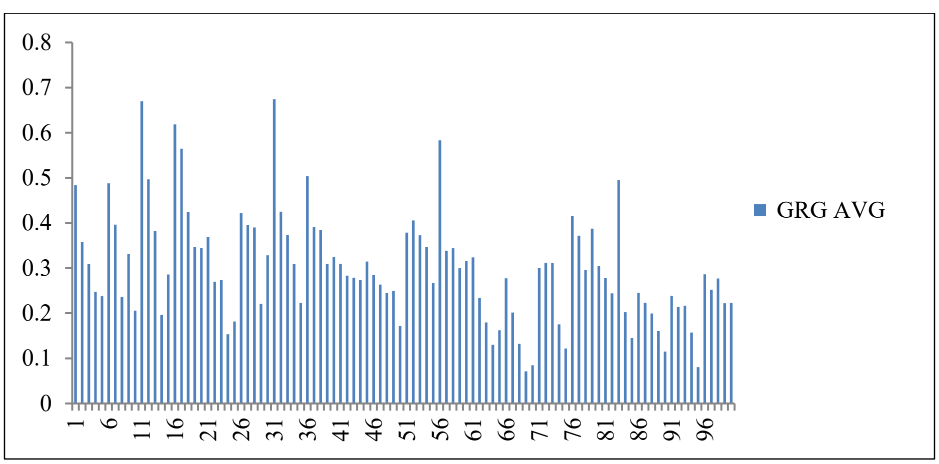


Fig. 8 GRG Avarage

*D. Sustainability of Ethanol Blending*

The sustainability aspect of ethanol blending was a pivotal consideration in this study. Ethanol, being a renewable biofuel derived from agricultural sources, presents an attractive alternative to fossil fuels. The findings underscore the potential for ethanol to reduce reliance on conventional petrol, thus contributing to energy security and sustainability. Furthermore, the reduction in harmful emissions aligns with global efforts to mitigate climate change and improve public health outcomes [13], [15].

However, it is essential to address the challenges associated with large-scale ethanol production, including land use changes, food security concerns, and the environmental impact of agricultural practices. Sustainable sourcing and production practices must be prioritized to ensure that the benefits of ethanol blending are not overshadowed by adverse effects. This aligns with the recommendations from previous studies advocating for a careful evaluation of biofuel sources and their environmental implications [17], [18].

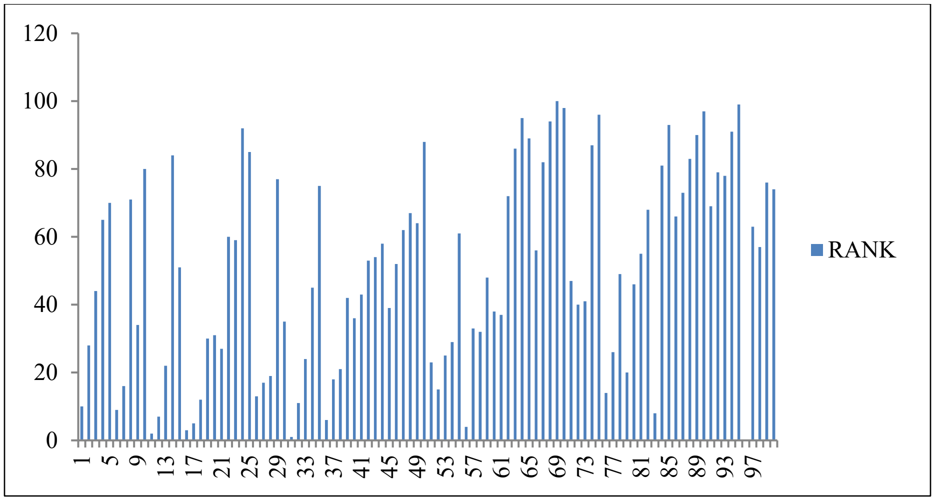


Fig. 9 Rank

TABLE I BEST OPERATING CONDITION

| E | Speed(rpm) | Comp. Ratio | HC | CO | CO2 | Nox |
|---|---|---|---|---|---|---|
| 10 | 1300 | 9 | 34 | 0.42 | 3.5 | 1560 |

TABLE II POOR OPERATING CONDITION

| E | Speed(rpm) | Comp. Ratio | HC | CO | CO2 | Nox |
|---|---|---|---|---|---|---|
| 30 | 1600 | 8 | 25 | 0.005 | 1.24 | 181 |

In conclusion, the investigation into ethanol blending presents a promising avenue for improving engine performance and reducing harmful emissions. The findings advocate for the adoption of optimized blends in the Indian automotive sector while also highlighting the need for sustainable practices in biofuel production. Future research should continue to explore advanced engine technologies and emission control strategies in conjunction with ethanol blending to maximize the environmental benefits of this renewable fuel source.

*E. Steps in Grey Relation Analysis*

1. *Define the Problem:* Clearly articulate the decision problem and the objectives.
2. *Identify Criteria and Alternatives:*

a. List all the criteria that will be used for evaluation.
b. Identify the alternatives you want to assess.

3. *Construct the Decision Matrix:* Create a decision matrix with alternatives in rows and criteria in columns. Populate it with the relevant data or scores for each alternative under each criterion.
4. *Normalization of Data:* Normalize the decision matrix to eliminate units of measurement. This can be done using various methods, such as min-max normalization or z-score normalization.
5. *Determine the Grey Relation Coefficients:* Calculate the Grey Relation Coefficient (GRC) for each alternative with respect to a reference or ideal solution. This is done using the formula:

$$\mathrm{GRC} = \frac{\Delta_{\min} + \xi \Delta_{\max}}{\Delta + \xi \Delta_{\max}}$$

where:
Δ is the absolute difference between the normalized value of the alternative and the reference.
Δmin and Δmax are the minimum and maximum differences, respectively.
ξ is a distinguishing coefficient (typically set between 0 and 1).

6. *Calculate the Grey Relation Grade:* The Grey Relation Grade (GRG) for each alternative is the average of the Grey Relation Coefficients across all criteria.
7. *Rank the Alternatives:* Rank the alternatives based on their Grey Relation Grades. The higher the grade, the

better the alternative is considered in relation to the criteria.

8. *Calculate the Grey Relation Grade:* The Grey Relation Grade (GRG) for each alternative is the average of the Grey Relation Coefficients across all criteria.
9. *Rank the Alternatives:* Rank the alternatives based on their Grey Relation Grades. The higher the grade, the better the alternative is considered in relation to the criteria.

## VII. CONCLUSION

This study provides a comprehensive examination of optimization, emphasizing its significance in enhancing engine performance and addressing complex problems across various fields. Optimization improves decision-making and resource allocation, with examples such as air-fuel ratio optimization demonstrating its impact on improving spark ignition engine efficiency [16]. A diverse array of optimization tools is explored, including multi-criteria decision-making (MCDM), which is crucial for addressing conflicting criteria in engine optimization [17]. The emergence of hybrid methods further enhances optimization performance by combining multiple approaches for superior results [19]. Additionally, mastering reference styles is vital for maintaining academic integrity, ensuring accurate attribution of sources, and enabling readers to verify research findings [18]. Optimization software such as the Analytic Hierarchy Process (AHP) and Grey Relation Analysis (GRA) is highlighted for its practical applications. AHP aids in prioritizing alternatives based on weighted criteria, while GRA evaluates relationships among various factors to identify optimal solutions [20]. These tools are particularly relevant in automotive applications, where they contribute to improving engine performance and reducing emissions [19]. Overall, the study underscores the critical role of optimization in driving advancements in research and practical applications across multiple disciplines.

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