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Ethanol as an Alternative Automotive Fuel: Performance, Emissions and Sustainability Implications

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Abstract -

The intensity concerns over fossil fuel dwindling, environmental decay and greenhouse gas emissions have sharpen the search for substitute and renewable fuels. Ethanol has emanated as a optimistic substitute for ordinary gasoline owing to its renewable nature, high octane rating and potential to reduce harmful vehicular emissions. This paper examines the production pathways, fuel properties, engine performance characteristics, and environmental benefits of ethanol–gasoline blends such as E10 and E85. Case studies from countries like Brazil and India highlight.

Keywords: **Ethenol Fuels, E10, E85, alternative fuels, renewable Energy, vehicular emissions.**

1.INTRODUCTION

Large scale implementation and practical feasibility. When ethanol offers notable advantages in minimizing carbon monoxide and hydrocarbon emissions , challenges like as lower density and impacts on economy fuel remains. Ethenol blending shows a viable and sustainable approach to falling petroleum dependence and mitigating vehicular emission pollution.

Transportation sector has raised serious issues regarding the depletion of conventional fossil fuel sources, energy security and environmental pollution. Spark Ignition (SI) engines which are powered by gasoline are important contributors to atmospheric pollution due to emission of pollutions such as carbon monoxide(CO), hydrocarbons(HC) unburned and nitrogen oxides (NO_x). This research has focused on oxygenated alternative fuels , particularly alcohol-based fuels, because of their ability to influence combustion behavior and reduce pollutant emissions. Ethenol is among the most promising renewable fuels because of its high octane number or rating , inherent oxygen content and suitability for use in conventional gasoline engines.

A considerable number of investigations have examined the effects of ethanol–gasoline blends on SI engine performance and emissions. Rosdi et al. [1] experimentally studied gasoline blends containing ethanol and fusel oil and found that increasing the ethanol fraction resulted in lower brake power and brake thermal efficiency. At the same time, brake-specific fuel consumption (BSFC) increased, which was mainly associated with the comparatively lower heating value of ethanol. Nevertheless, the blended fuels produced reductions in exhaust gas temperature as well as NO_x, CO, and HC emissions, indicating their potential environmental benefits. Ansari et al. [2] investigated alcohol–gasoline blends with respect to engine performance and noise characteristics. Their results showed a minor decrease in power and an increase in fuel consumption following alcohol addition. However, improved combustion stability and reduced pollutant emissions were also reported, demonstrating the compromise between engine performance and emission reduction associated with alcohol blending.

Computational techniques have increasingly been applied to the analysis and optimization of alternative fuel blends. Farooq Shaik et al. [3] employed artificial neural networks (ANN) together with response surface methodology (RSM) for predicting and optimizing the performance and emission parameters of an SI engine fueled with gasoline–ethanol–methanol (GEM) mixtures. The investigation indicated that appropriately optimized alcohol proportions could achieve substantial emission reductions without causing unacceptable deterioration in engine performance. This work demonstrates the usefulness of numerical and statistical tools in determining suitable fuel compositions. Deshpande et al. [4] investigated gasoline–ethanol mixtures at different engine speeds and loads. An increase in ethanol concentration was associated with a gradual reduction in brake power and a rise in

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BSFC. Conversely, CO and HC emissions were generally reduced over the tested operating range, suggesting the usefulness of ethanol blends for controlling exhaust pollutants.

The application of ethanol blends in two-wheelers has also received significant attention. Gupta et al. [5] examined ethanol-containing gasoline using a chassis dynamometer and reported that the blends could operate effectively as flex-fuel alternatives. Considerable reductions in CO and HC emissions were achieved, although increasing ethanol concentration resulted in greater fuel consumption. Such findings are particularly significant in regions where two-wheelers constitute a substantial portion of the transportation sector. Mara and Nuarsa [6] examined ethanol–gasoline blends in a 125 cc four-stroke engine and similarly reported improved exhaust emission characteristics accompanied by an increase in fuel consumption. Their study confirmed that the advantages of ethanol blending are also applicable to relatively small-displacement engines.

Research comparing different alcohol-based fuels has provided additional insight into their respective advantages. Elfasakhany [7] compared ethanol–butanol–gasoline mixtures and reported that ethanol-containing fuels provided greater reductions in emissions, whereas butanol demonstrated advantages in terms of energy-related performance because of its higher calorific value. Usman et al. [8] investigated ethanol and methanol–ethanol mixtures and reported that ethanol-based fuels could provide a reasonable balance among engine performance, emission characteristics, and renewable-fuel considerations. Rojas-Reinoso et al. [9] examined gasoline–ethanol mixtures under urban driving conditions and observed considerable reductions in CO and HC emissions, indicating their potential contribution to improved urban air quality. Ye et al. [10] evaluated different ethanol blending levels in electronically fuel-injected engines and reported improvements in combustion behavior and exhaust emissions when an appropriate ethanol concentration was selected.

Researchers have also explored the use of additives and combined fuel formulations to further improve the characteristics of alcohol–gasoline blends. Pirouzfar et al. [11] investigated alcohol fuels containing metal-oxide additives and observed improvements in combustion characteristics together with reductions in pollutant emissions. Elshenawy et al. [12] used combustion simulation techniques to investigate ethanol–gasoline mixtures and reported that ethanol could enhance flame development while limiting the formation of certain pollutants. Venktesh Kumar and Jain [13] assessed gasoline engines operating with different ethanol concentrations and reported that low-to-moderate ethanol blending levels provided a suitable combination of engine performance and emission characteristics.

The findings reported in previous investigations generally indicate that incorporating ethanol into gasoline can provide substantial reductions in several harmful exhaust emissions, although improvements in environmental performance may be accompanied by penalties in power output and fuel economy. The magnitude of these effects depends on factors such as ethanol concentration, engine operating conditions, fuel-injection system, and engine configuration. Therefore, determining an appropriate blending ratio remains important for achieving an acceptable balance between performance, fuel consumption, and emissions. In this context, the present investigation focuses on the experimental evaluation of SI engine performance and exhaust emissions using different ethanol–gasoline blend ratios, with the objective of identifying blend conditions that provide improved emission characteristics without causing excessive deterioration in engine performance.

2. METHOD AND STUDY

The investigation employs a combined experimental and analytical approach to examine the effects of ethanol–gasoline mixtures on the performance and exhaust emissions of a spark ignition (SI) engine. Different proportions of ethanol are incorporated into gasoline, and their influence on key engine performance indicators and emission parameters is assessed under controlled test conditions. The adopted methodology enables a systematic comparison of the fuel blends and facilitates the identification of their effects on engine operation, fuel consumption, and exhaust pollutant formation.

1) Fuel Preparation

Test fuels were formulated by mixing commercially available gasoline with ethanol according to predetermined volumetric proportions. Three ethanol-containing fuel samples, designated as E10, E20, and E30, were prepared, corresponding to ethanol concentrations of 10% , 20%, and 30% by volume, respectively with the remaining fraction consisting of gasoline. Unblended gasoline (E0) was selected as the baseline fuel to facilitate comparative assessment. Prior to conducting the engine experiments, each prepared mixture was adequately agitated to obtain a uniform and consistent fuel composition.

2) Engine Test Setup

The experiments were conducted on a single-cylinder, four-stroke, spark ignition engine coupled with an eddy current dynamometer for load control. The engine was operated at a constant speed while varying the load conditions to simulate realworld operating scenarios. Standard engine instrumentation was used to measure parameters such as fuel consumption, brake power, exhaust gas temperature, and air–fuel ratio.

The ethanol–gasoline blends were prepared on a volumetric basis. The volume of ethanol and gasoline required for each blend was calculated using the following relation:

Ethanol %= Ve/Vt x100

Here V_e= Volume of ethanol(ml)

V_t= Total volume fuel blend (ml)

Fuel Blend	Ethanol (ml)	Gasoline (ml)	Total Volume (ml)
Gasoline	0	1000	1000
E10	100	900	1000
E20	200	800	1000
E30	300	700	1000

3) Experimental Procedure

Before conducting the experiments, the engine was allowed to warm up until steady-state operating conditions were achieved. Tests were first carried out using pure gasoline to establish baseline performance and emission data. Subsequently, the engine was operated with ethanol–gasoline blends (E10, E20, and E30) under identical conditions. For each fuel blend, data were recorded at multiple load conditions to ensure repeatability and reliability of results.

Single cylinder, four stroke, VCR (Variable Compression Ratio) Research engine

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4) Performance Parameters Evaluation

Engine performance was assessed by considering the following important parameters:

- **Brake Horsepower (BHP):** The engine's brake power output was determined using the measured torque and corresponding engine speed.
- **Brake Specific Fuel Consumption (BSFC):** BSFC was obtained by relating the rate of fuel consumed to the brake power generated by the engine.
- **Brake Thermal Efficiency (BTE):** Thermal efficiency was evaluated by comparing the useful brake power produced by the engine with the energy supplied through the fuel.

The measured performance parameters were analyzed for the different ethanol–gasoline mixtures and compared with the baseline gasoline fuel. This comparison was used to determine how changes in ethanol concentration affect engine efficiency, power generation, and fuel consumption.

These parameters were compared across different ethanol blends to assess the influence of ethanol concentration on engine efficiency and fuel utilization.

5) Emission Analysis

The exhaust characteristics of the engine were investigated with the help of a properly calibrated gas analyzer. The instrument was used to quantify major gaseous pollutants, including carbon monoxide (CO), unburned hydrocarbons (HC), and nitrogen oxides (NO_x)**.** In addition, the exhaust gas temperature (EGT) was monitored as an indicator of combustion and heat-release behaviour . For each test fuel, emission data were recorded only after the engine attained stable operating conditions, thereby minimizing fluctuations and improving the reliability and consistency of the experimental measurements.

6) Data Analysis and Validation

The experimental data obtained were analyzed by comparing the performance and emission parameters of ethanol-blended fuels with those of pure gasoline. Percentage variations in BHP, BSFC, BTH, exhaust gas temperature, and emissions were calculated to quantify the effects of ethanol blending. The results were then compared with trends reported in the existing literature to validate the findings.

7) Scope and Limitations

The study focuses on low to medium ethanol blending ratios suitable for use in conventional SI engines without major modifications. Factors such as long-term engine durability, cold-start performance, and lifecycle environmental impacts were beyond the scope of the present investigation and are recommended for future research.

3.CONCLUSIONS

The present study investigated the effects of ethanol–gasoline blended fuels on the performance and emission characteristics of a spark ignition engine under controlled operating conditions. Ethanol blends of E10, E20, and E30 were evaluated and compared with conventional gasoline to assess their suitability as alternative fuels for Automotives. The experimental observations indicate that increasing ethanol content in gasoline leads to a gradual reduction in brake horsepower and brake thermal efficiency, primarily due to the lower calorific value of ethanol. Correspondingly, brake specific fuel consumption increased with higher ethanol blend ratios, reflecting the greater fuel quantity required to produce the same power output. These trends are consistent with observations reported in earlier studies and confirm the inherent trade-off between engine performance and fuel economy when using ethanol-blended fuels. Despite the slight performance penalties, ethanol blending demonstrated significant environmental benefits. The use of ethanol–gasoline blends resulted in noticeable reductions in carbon monoxide, hydrocarbon, and nitrogen oxide emissions compared to pure gasoline operation. The decrease in exhaust gas temperature further indicated improved combustion behavior and lower peak combustion temperatures. These emission reductions can be attributed to the oxygenated nature of ethanol, which promotes more complete combustion and reduces the formation of harmful pollutants. the tested blends, low to medium ethanol concentrations such as E10 and E20 offered a favorable balance between performance retention and emission reduction, making them particularly suitable for use in conventional spark ignition engines without major modifications. Higher blends such as E30, while providing greater emission benefits, showed more pronounced increases in fuel consumption and reductions in engine power. Overall, the findings of this study confirm that ethanol–gasoline blending is a

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practical and sustainable approach to reducing petroleum dependence and mitigating vehicular emissions. With appropriate optimization of blend ratios and engine operating parameters, ethanol can play a significant role in getting cleaner and more sustainable transportation systems. Future research should focus on long-term durability studies, cold-start performance, and the integration of advanced engine control strategies to further enhance the benefits of ethanol-blended fuels.

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