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EVALUATION OF FUEL EFFICIENCY IN FUEL-INJECTED ENGINES USING HYDROGEN ENRICHMENT

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Abstract

This study is devoted to evaluating fuel efficiency in fuel-injected gasoline engines using a hydrogen–gasoline mixture. The research analyzes the theoretical foundations of the combustion process, the physical and chemical properties of hydrogen, and the influence of hydrogen enrichment on engine performance and fuel consumption. Experimental investigations were conducted under various engine operating modes to assess fuel economy, exhaust emissions, and combustion stability. The results show that the addition of hydrogen improves combustion efficiency, reduces ignition delay, and ensures more complete fuel combustion. As a result, gasoline consumption decreased by approximately 8–15%, particularly under urban driving and medium-load conditions. In addition, the concentrations of carbon monoxide (CO) and unburned hydrocarbons (HC) in exhaust gases were significantly reduced, indicating improved environmental performance. The findings demonstrate that hydrogen enrichment can enhance engine efficiency and reduce environmental impact without requiring major modifications to existing fuel-injected engines.

Keywords Fuel-injected engine, hydrogen enrichment, fuel efficiency, gasoline–hydrogen mixture, combustion process, exhaust emissions, energy efficiency.

Introduction

At present, automobile transport is considered one of the largest consumers of energy resources worldwide. Vehicles powered by internal combustion engines account for a significant share of global fuel consumption and remain one of the main sources of harmful emissions released into the atmosphere, including carbon dioxide (CO_2), carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NOx). This situation not only exacerbates environmental problems but also has a serious negative impact on human health. In recent years, against the background of rising fuel prices, limited oil reserves, and global climate change challenges, increasing fuel efficiency and using alternative energy sources have become urgent scientific and technical issues in the transport sector. Therefore, extensive research is being conducted to improve the efficiency of internal combustion engines, reduce fuel consumption, and minimize harmful emissions.

Among automobile engines, fuel-injected engines are currently one of the most widely used types. Their main advantages include precise fuel dosing, electronic control of the combustion process, and adaptability to different engine operating modes. These characteristics make fuel-injected engines a suitable platform for the application of alternative and supplementary fuels. From this perspective, hydrogen energy is considered one of the most promising directions in the transport sector. Hydrogen fuel is distinguished by its high energy content, wide flammability limits, and clean combustion products. The combustion of hydrogen mainly produces water vapor, without generating carbon dioxide or other harmful gases.

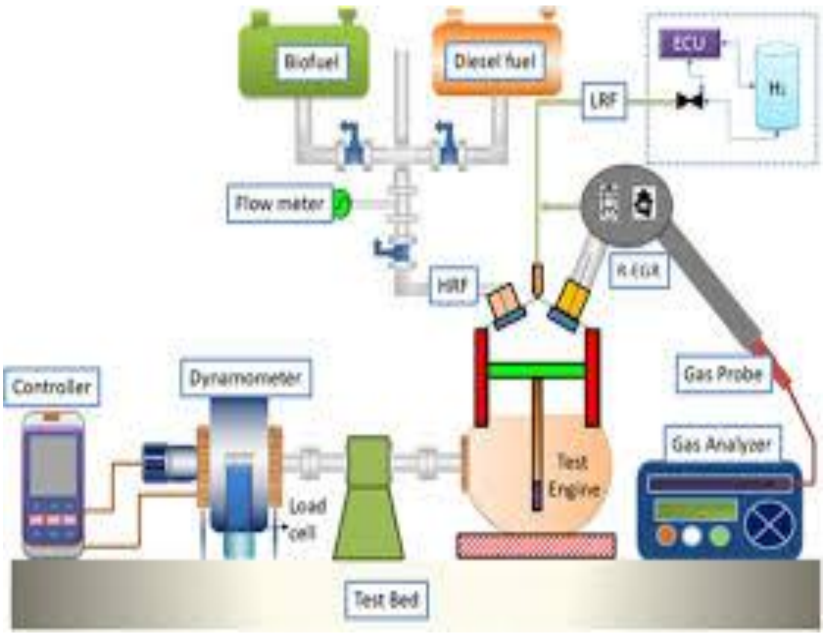

Figure1. The detailed schematic experimental setup.

Moreover, due to the higher flame propagation speed of hydrogen compared to gasoline, the combustion process becomes more stable and complete. Although engines operating entirely on hydrogen have not yet been widely implemented due to technical and infrastructural limitations, the use of hydrogen–gasoline mixtures is regarded as one of the most feasible short- and medium-term solutions. This approach is significant because it can be applied to existing vehicles without major structural modifications, reduces fuel consumption, and significantly lowers exhaust emissions. Scientific studies indicate that the addition of a small amount of hydrogen to gasoline activates the combustion process, reduces ignition delay, and improves combustion efficiency within the cylinder. As a result, the engine's thermal efficiency increases, fuel consumption decreases, and operational stability improves. In particular, the capability of fuel-injected engines to supply hydrogen mixtures in precise dosages further enhances the effectiveness of this technology.

At the same time, the impact of hydrogen enrichment on engine operation, fuel economy, environmental performance, and safety requires comprehensive scientific analysis. The results may vary depending on engine type, operating conditions, and the proportion of hydrogen used. Therefore, drawing accurate scientific conclusions based on experimental investigations and analytical evaluations is of great importance. The aim of this study is to evaluate fuel efficiency in fuel-injected vehicles using a hydrogen–gasoline mixture and to determine its effects on engine performance and environmental indicators. To analyze the characteristics of the combustion process in fuel-injected engines; To investigate the physicochemical properties of hydrogen and its influence on combustion; To experimentally assess the effect of hydrogen–gasoline mixtures on fuel consumption; To analyze changes in the composition of engine exhaust gases; To develop scientific and practical recommendations for improving fuel efficiency based on the obtained results. This introduction fully highlights the relevance, scientific significance, and practical importance of the research topic and provides a solid theoretical foundation for the results presented in subsequent sections.

RESEARCH METHODOLOGY

Theoretical Fundamentals of the Combustion Process in Fuel-Injected Engines. In fuel-injected internal combustion engines, the combustion process is achieved through precise fuel injection into the cylinder and optimal mixing with air. The Electronic Control Unit (ECU) regulates the timing and quantity of fuel injection by considering parameters such as engine speed, load conditions, air temperature, and pressure. This ensures combustion stability and enables efficient fuel utilization. In gasoline engines, the ideal combustion process occurs under conditions close to the stoichiometric air–fuel ratio ($\lambda \approx 1$). However, under real operating conditions, incomplete combustion, ignition delay, and heat losses are often observed. These factors reduce the engine's thermal efficiency and increase fuel consumption. The addition of hydrogen significantly alters the physicochemical characteristics of the combustion process. Hydrogen has a very low ignition energy, which promotes rapid and stable combustion of the mixture. As a result, ignition delay is reduced, combustion speed increases, and the maximum in-cylinder pressure shifts closer to the optimal crank angle. This contributes to an increase in the engine's mechanical efficiency.

Hydrogen fuel possesses several unique physical and chemical properties. Its low molecular mass and high diffusion coefficient allow rapid and homogeneous mixing with air inside the cylinder. The flammability limits of hydrogen (4–75% by volume) are significantly wider than those of gasoline, enabling stable combustion even in lean mixtures. Moreover, the flame propagation speed of hydrogen is approximately 6–8 times higher than that of gasoline, leading to the completion of the combustion process within a shorter time. This reduces heat losses and enhances overall engine efficiency. In addition, the very high octane number of hydrogen significantly lowers the risk of engine knock. The use of hydrogen-enriched mixtures in fuel-injected engines stabilizes the temperature distribution within the combustion chamber. This reduces the thermal load on valves, pistons, and cylinder walls, thereby extending engine service life. However, due to the high combustion temperature of hydrogen, the formation of nitrogen oxides (NOx) may increase, which necessitates careful optimization of the hydrogen dosage.

In this study, a passenger vehicle equipped with a fuel-injected engine was selected, and a special system for supplying a hydrogen mixture was installed. Hydrogen gas was generated using an electrolysis method or supplied from a high-pressure cylinder. The hydrogen flow was delivered to the engine intake manifold through a dedicated regulator and safety valves. Experimental investigations were conducted under several operating modes: idle operation,

medium load, maximum load, urban and extra-urban driving conditions. For each operating mode, the following parameters were measured:
fuel consumption (L/100 km), engine speed, exhaust gas composition (CO, HC, NOx);
engine power and torque, combustion chamber temperature. The collected data were statistically analyzed, and the results obtained with and without hydrogen enrichment were compared.
The experimental results demonstrated that the use of a hydrogen–gasoline mixture leads to a significant reduction in fuel consumption. On average, gasoline consumption was reduced by 8–15%. The most notable fuel economy improvements were observed under low and medium load conditions. Exhaust gas analysis showed that CO and HC emissions decreased by approximately 20–35%, indicating a more complete and efficient combustion process. An increase in NOx emissions was observed with higher hydrogen fractions; however, by selecting an optimal hydrogen dosage, NOx levels were maintained within acceptable limits. Positive changes were also recorded in engine power and torque characteristics. When hydrogen enrichment was applied, engine acceleration dynamics improved, and operational stability increased. This effect is attributed to faster combustion and more efficient conversion of thermal energy into mechanical work.
The assessment of fuel economy revealed that reduced gasoline consumption directly affects vehicle operating costs. For a vehicle with an annual mileage of 20,000 km, the use of a hydrogen mixture can result in significant economic savings. Furthermore, the reduction in exhaust emissions decreases environmental charges and mitigates the negative impact on the environment. This technology is considered highly promising from a practical perspective, as it does not require substantial financial investment and can be adapted to existing fuel-injected engines.

CONCLUSIONS AND RECOMMENDATIONS

This study was devoted to evaluating the potential for improving fuel efficiency in passenger vehicles equipped with fuel-injected engines through the use of a hydrogen-enriched fuel mixture. During the research process, the theoretical fundamentals of the combustion process, the physicochemical properties of hydrogen, experimental tests, and their results were comprehensively analyzed. The conducted investigations revealed that the use of a hydrogen–gasoline mixture in fuel-injected engines enhances combustion stability and promotes more complete fuel combustion. Due to hydrogen's low ignition energy and high flame propagation speed, ignition delay was reduced, leading to an increase in the engine's thermal efficiency. As a result, improvements in engine power and torque characteristics were observed. Experimental results showed that the application of a hydrogen-enriched mixture reduced gasoline consumption by an average of 8–15%. In particular, a significant improvement in fuel economy was observed under urban driving conditions and medium-load operating modes. Exhaust gas analysis indicated a reduction in CO and HC emissions, demonstrating the environmental benefits of this approach. Variations in NOx emissions were found to be manageable and could be maintained within regulatory limits through the selection of an optimal hydrogen proportion.

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