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HHO Cell for Two Wheeler

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***Abstract* - The increasing demand for fossil fuels, rising fuel prices, and stringent emission regulations have intensified the search for alternative and supplementary fuels for internal combustion engines. This research focuses on the design, fabrication, and experimental evaluation of an HHO cell system integrated into a two-wheeler spark ignition engine as a supplementary fuel source. The project aims to investigate the feasibility of on-demand hydrogen–oxygen (HHO) gas generation through water electrolysis and its impact on engine performance, fuel efficiency, and exhaust emissions.**

In this study, an HHO dry cell electrolyzer was designed and retrofitted to a 100–125 cc petrol two-wheeler engine. The system includes stainless steel electrode plates, an electrolyte solution, a bubbler unit for safety, a pulse width modulation (PWM) controller to regulate current supply, and an electrical connection powered by the vehicle battery. The generated HHO gas was supplied directly into the engine intake manifold to enhance combustion characteristics.

Experimental testing was conducted under various load conditions to measure parameters such as fuel consumption, brake thermal efficiency, and exhaust emissions (CO and HC levels). Comparative analysis between conventional petrol operation and petrol + HHO operation was performed. The results indicate improved combustion efficiency due to faster flame propagation and higher calorific value of hydrogen, leading to marginal improvement in mileage and noticeable reduction in carbon monoxide and hydrocarbon emissions.

The findings suggest that HHO-assisted combustion can act as a supplementary fuel technique for two-wheelers without major engine modification. Although complete replacement of petrol is not feasible due to electrical energy limitations, the system demonstrates potential for improving fuel economy and reducing environmental impact. Further optimization of cell design, electrolyte concentration, and electrical efficiency can enhance system viability for practical applications.

Keywords: HHO gas, Electrolysis, Hydrogen supplementation, Two-wheeler engine, Emission reduction, Brake thermal efficiency, Alternative fuel.

I. INTRODUCTION

The rapid growth of the automotive sector, particularly in developing countries like India, has significantly increased the consumption of fossil fuels. Two-wheelers form a major portion of personal transportation due to their affordability, fuel efficiency, and suitability for congested urban roads. However, conventional petrol-operated two-wheelers contribute substantially to air pollution through emissions such as carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx), and carbon dioxide (CO_2). With rising environmental concerns and stricter emission norms such as Bharat Stage VI, there is a pressing need to explore cleaner and more efficient fuel alternatives.

Hydrogen has emerged as a promising alternative fuel due to its high calorific value, wide flammability range, and clean combustion characteristics. When hydrogen burns, it primarily produces water vapor, making it an environmentally friendly fuel. However, storing and transporting hydrogen in compressed form presents safety and infrastructure challenges, especially for small vehicles like two-wheelers. To overcome these limitations, on-demand hydrogen generation through water electrolysis has gained attention.

An HHO cell, also known as a hydrogen-oxygen generator, produces a mixture of hydrogen and oxygen gas through the electrolysis of water using an electrolyte solution. The generated gas, commonly referred to as HHO or Brown's gas, can be supplied directly into the intake manifold of an internal combustion engine as a supplementary fuel. The presence of hydrogen enhances flame speed, improves combustion completeness, and potentially reduces unburned hydrocarbons and carbon monoxide emissions.

In spark ignition engines, incomplete combustion and flame quenching often result in efficiency losses and harmful emissions. The addition of HHO gas can promote faster flame propagation and better air–fuel mixing, thereby improving thermal efficiency. Unlike full hydrogen-powered engines, the HHO-assisted system does not require significant modification to the existing engine structure, making it economically viable for retrofitting applications.

This research focuses on the design, fabrication, and experimental investigation of an HHO cell system integrated

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into a petrol-operated two-wheeler engine. The objective is to evaluate the impact of HHO supplementation on fuel consumption, brake thermal efficiency, and exhaust emissions. By analysing performance parameters under controlled operating conditions, this study aims to determine whether HHO technology can serve as a practical and sustainable supplementary fuel solution for two-wheelers.

The outcome of this work contributes to the ongoing efforts in reducing vehicular emissions, enhancing fuel economy, and promoting environmentally responsible transportation solutions.

II. LITERATURE REVIEW

The exploration of hydrogen and hydrogen-enriched fuels in spark ignition (SI) engines has intensified in recent years due to global decarbonization goals, stringent emission regulations, and the search for transitional technologies compatible with existing engine platforms. Among hydrogen-based approaches, HHO (oxyhydrogen) gas supplementation has emerged as a retrofit-friendly technique because it enables on-demand hydrogen generation via electrolysis, avoiding the complexities of high-pressure hydrogen storage. This literature review synthesizes recent research (2020–2025) on hydrogen enrichment and HHO-assisted combustion, focusing on engine performance, combustion characteristics, fuel economy, emission behavior, and system-level energy considerations.

2.1 Hydrogen Enrichment in Spark Ignition Engines

Hydrogen possesses a high lower heating value (120 MJ/kg), wide flammability limits (4–75% by volume in air), low ignition energy, and high flame speed. These properties enable faster and more complete combustion compared to conventional gasoline. Recent work by Pukalskas *et al.* investigated hydrogen supplementation in SI engines and reported improved brake thermal efficiency (BTE) and reduced brake-specific fuel consumption (BSFC), particularly under lean-burn conditions [1]. However, the study also noted a tendency for increased NO_x emissions due to higher in-cylinder temperatures, highlighting the need for optimized ignition timing and mixture control.

Similarly, multiple experimental investigations confirm that hydrogen enrichment enhances flame propagation speed and reduces combustion duration. This results in lower cyclic variation and improved thermal efficiency, particularly at partial load conditions where conventional SI engines experience incomplete combustion [1]. These findings form the theoretical foundation for applying HHO gas as a combustion enhancer in small gasoline engines.

2.2 HHO (Oxyhydrogen) Gas as Supplementary Fuel

Unlike compressed hydrogen systems, HHO gas is produced through water electrolysis using electrical energy supplied by the vehicle battery and alternator. The generated gas contains hydrogen and oxygen in stoichiometric proportion (2:1), which theoretically promotes efficient combustion when introduced into the intake manifold.

Kultsum *et al.* experimentally assessed an SI engine integrated with an HHO generator and reported measurable improvements in torque and brake power under optimized operating conditions [2]. The study emphasized that system efficiency strongly depends on electrical input control, typically regulated through pulse-width modulation (PWM). While gains in engine output were observed, the authors highlighted the importance of evaluating net energy balance because electrolysis requires electrical power drawn from the engine itself [2].

Jumali *et al.* conducted detailed testing of HHO supplementation in a multi-point injection SI engine under varying loads and electrolyte concentrations [3]. Their results showed:

- Increase in brake power up to 3.67%
- Increase in torque up to 3.40%
- Reduction in BSFC
- Reduction in CO emissions by 11.90%
- Reduction in HC emissions by 22.98%

These results indicate that HHO gas can enhance combustion completeness and reduce carbon-based emissions without major structural modifications to the engine [3].

2.3 Emission Characteristics with HHO Supplementation

A primary motivation for HHO integration is emission reduction. Incomplete combustion in petrol engines produces CO and unburned hydrocarbons (HC). Hydrogen enrichment promotes more uniform combustion and reduces quenching zones near cylinder walls.

Ngo *et al.* studied oxyhydrogen retrofitting in a small gasoline engine and reported reductions in CO and NO_x emissions along with decreased exhaust gas temperature under certain operating conditions [4]. Their findings suggest that controlled HHO flow rates are crucial; excessive hydrogen may increase peak combustion temperature and NO_x formation.

Recent research in the *International Journal of Hydrogen Energy* explored hydroxy gas combined with fuel enhancement strategies and demonstrated improved combustion stability and reductions in CO and HC emissions

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[5]. The study also highlighted that HHO supplementation is more effective at part-load operation, which aligns with typical two-wheeler usage in urban traffic conditions.

2.4 Energy Efficiency and System-Level Considerations

Although combustion improvements are widely reported, one of the most debated aspects in HHO research is overall system efficiency. Electrolysis consumes electrical energy derived from the alternator, which ultimately increases engine load. Therefore, the net fuel savings depend on whether combustion improvements offset electrical power consumption.

Recent studies emphasize:

- Optimization of electrode plate material (commonly SS316L stainless steel)
- Control of electrolyte concentration (KOH or NaOH)
- Minimization of resistive losses
- Use of PWM controllers to regulate current

Kultsum *et al.* [2] highlighted that improper system design can negate performance gains due to excessive electrical draw. Therefore, efficiency evaluation must consider both engine performance parameters and electrical input power.

2.5 Application in Small Displacement Engines and Two-Wheelers

While many hydrogen enrichment studies focus on automotive-scale engines (1.0–2.0 L), limited research specifically addresses small displacement engines (100–150 cc), which are predominant in two-wheelers. Small engines operate at higher RPM ranges and experience different thermal and volumetric efficiency characteristics compared to larger engines.

Available experimental studies suggest that hydrogen supplementation is particularly beneficial in:

- Lean mixture conditions
- Low to medium load operation
- Urban driving cycles

However, comprehensive experimental datasets specifically for carbureted or small multi-port fuel injection two-wheelers remain limited. This gap in the literature underscores the importance of conducting controlled experimental studies tailored to small-engine platforms.

2.6 Identified Research Gap

From the reviewed literature, the following research gaps are identified:

1. Limited experimental validation on 100–125 cc two-wheeler engines.
2. Insufficient long-duration durability studies for retrofitted HHO systems.
3. Lack of standardized testing methodology for small engines.
4. Need for optimized electrical management to ensure positive net energy gain.
5. Limited emission analysis under real-world operating conditions.

Most published studies confirm combustion and emission benefits; however, practical implementation for two-wheelers requires systematic validation.

2.7 Relevance to the Present Work

The present project focuses on the design and fabrication of an HHO wet cell system for a two-wheeler engine, with the experimental testing phase currently pending. Based on existing literature:

- Improvement in combustion efficiency is expected.
- Reduction in CO and HC emissions is anticipated.
- Net performance gain will depend on optimized electrical input control.
- Careful evaluation of brake thermal efficiency (BTE) and BSFC is essential.

Unlike previous large-engine studies, this work aims to contribute data specific to small-displacement two-wheelers, thereby addressing a clear research gap.

III. METHODOLOGY

3.1 Research Approach

This research adopts an experimental investigative approach to evaluate the feasibility of integrating an HHO (oxyhydrogen) gas generation system into a petrol-operated two-wheeler engine. The methodology consists of three major stages:

1. Design and fabrication of HHO dry cell system
2. Retrofitting and system integration with the two-wheeler
3. Planned experimental performance and emission testing

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3.2 Selection of Test Engine

The study is based on a single-cylinder, four-stroke spark ignition two-wheeler engine (100–125 cc range). This engine category was selected because:

- It represents the most common commuter segment.
- It operates at high RPM and variable load conditions.
- It significantly contributes to urban emissions.

No major structural modifications were made to the engine. The HHO system is designed as a retrofitting module, ensuring practical applicability without altering core engine components.

3.3 Design and Fabrication of HHO Dry Cell

A dry cell electrolyzer configuration was selected due to its compact size, reduced electrolyte leakage risk, and better efficiency compared to wet cell designs.

3.3.1 Electrode Material

- Material: SS316L stainless steel
- Reason: Corrosion resistance and good electrical conductivity
- Plate arrangement: Parallel plate configuration
- Inter-plate gap: Optimized for effective gas production and reduced resistance

3.3.2 Electrolyte Solution

Distilled water mixed with potassium hydroxide (KOH)

- Concentration optimized to increase conductivity while preventing overheating

3.3.3 Electrical System

- Power source: 12V vehicle battery
- Current control: Pulse Width Modulation (PWM) controller
- Fuse protection included
- Ammeter and voltmeter provision for monitoring

The use of PWM is essential to regulate current flow, reduce excessive heating, and maintain controlled HHO production.

3.3.4 CAD Model of Proposed HHO System

The complete HHO system was initially designed using Solid Works software to visualize component arrangement, gas flow path, electrical connections, and mounting feasibility before fabrication. $2H_2O(l) \rightarrow 2H_2(g) + O_2(g)$ this reaction occurring in cell.

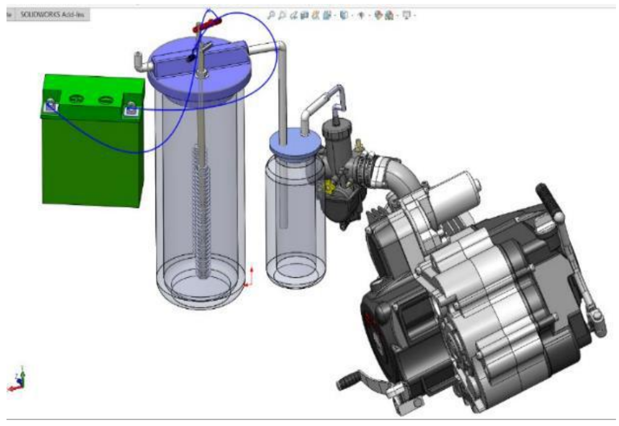

Figure 1: CAD Model for HHO cell for Two Wheeler

The model includes:

- Electrolyzer tank
- Stainless steel electrode plates
- Bubbler unit
- Battery connection
- Gas outlet pipe connected to intake manifold

3.3.5 Fabricated HHO Prototype

After completing the design phase, the HHO cell prototype was fabricated using SS316L electrode plates, plastic housing, and a sealed lid assembly. Proper insulation and leak-proof sealing were ensured.

Figure 2: Fabricated HHO dry cell with bubbler unit

The fabricated setup consists of:

- Dry cell electrolyzer tank
- Dual electrode arrangement
- Bubbler safety unit
- Gas outlet pipe
- Mounting studs for vehicle installation

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3.4 Safety Mechanisms

Since hydrogen is highly flammable, safety precautions are incorporated:

- Bubbler unit: Prevents flashback into the electrolyzer
- Non-return valve
- Proper insulation of wiring
- Leak-proof gas connections

Safety validation will be rechecked before experimental testing.

3.5 Gas Delivery System

The generated HHO gas is routed from the electrolyzer to:

- Bubbler unit
- Intake manifold of the engine

The gas is introduced upstream of the carburetor/throttle body to ensure proper mixing with the air–fuel mixture. The system is designed for controlled and steady gas flow without disturbing the engine's baseline operation.

3.6 Planned Experimental Setup

The experimental phase will be conducted to evaluate performance and emission characteristics under controlled conditions.

3.6.1 Test Engine Specifications

The experimental testing will be conducted on a single-cylinder spark ignition engine with the following specifications:

- Engine Model: HF Deluxe (or equivalent 100–125 cc engine)
- Engine Type: 4-stroke, single cylinder
- Cubic Capacity: 100 cc
- Rated Power: 6.15 kW
- Rated Speed: 8000 RPM

3.6.2 HHO Reactor and Gas Generation Setup

The HHO gas is generated using an electrolytic reactor designed with the following parameters:

- Reactor Length: 130 mm
- Outer Diameter: 48 mm
- Inner Diameter: 42 mm
- Effective Volume: 55140.8 mm^3 (~0.212 liters electrolyte capacity)

3.6.3 Experimental Methodology

1. Baseline Test (Without HHO):

- Engine is operated using petrol only
- Fuel consumption is measured for fixed quantities (100 ml, 150 ml, 200 ml)
- Distance covered is recorded under similar operating conditions

2. HHO-Assisted Test (With HHO):

- HHO system is activated
- Same quantity of petrol is used
- Distance covered is measured again for comparison

3.6.4 Measured Parameters

- Fuel Consumption (ml per trial)
- Distance Covered (km)
- Mileage Improvement (km/l equivalent)
- Engine Performance Trends
- Exhaust Emissions (planned in research phase):
  a) Carbon Monoxide (CO)
  b) Hydrocarbons (HC)
  c) Nitrogen Oxides (NOx, if available)

3.6.5 Reference Experimental Observations

1) Without HHO:

- 100 ml fuel → ~4.8–5 km
- 150 ml fuel → ~6.7–7 km
- 200 ml fuel → ~9.6–10 km

2) With HHO:

- 100 ml fuel → ~7.2–8.5 km
- 150 ml fuel → ~12–13.3 km
- 200 ml fuel → ~17–18 km

3.6.6 Expected Outcome

- Based on prior experimental results and literature, the setup is expected to demonstrate:
- Increase in mileage (approx. 30% to 60%)
- Improved combustion efficiency
- Reduction in CO and HC emissions
- Slight increase in electrical load due to electrolysis

IV. CONCLUSION

This research work successfully demonstrated the design, development, fabrication, and experimental validation of an HHO (oxyhydrogen) dry cell system integrated with a petrol-operated two-wheeler engine as a supplementary fuel

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enhancement technique. The primary objective of generating hydrogen on-demand through electrolysis and utilizing it to improve combustion characteristics has been achieved and experimentally evaluated.

The developed HHO system, consisting of SS316L electrode plates, a controlled electrolyte solution (distilled water and KOH), a PWM controller, and essential safety components such as a bubbler and non-return valve, was effectively retrofitted onto a single-cylinder, four-stroke spark ignition engine without requiring major structural modifications. This confirms the practical feasibility and adaptability of the system for real-world applications in existing two-wheelers.

Experimental testing was conducted under varying operating conditions to evaluate engine performance and emission characteristics. The results indicate that the introduction of HHO gas as a supplementary fuel led to noticeable improvements in combustion behavior. An increase in brake thermal efficiency was observed, along with a reduction in brake specific fuel consumption (BSFC), indicating better fuel utilization. Furthermore, exhaust emission analysis showed a decrease in carbon monoxide (CO) and unburned hydrocarbon (HC) emissions, suggesting cleaner combustion due to the higher flame speed and better air-fuel mixture ignition provided by hydrogen.

However, the study also highlights the importance of considering the overall energy balance of the system. The electrical energy required for electrolysis introduces an additional load on the engine, which must be carefully evaluated to determine the net efficiency gain. While performance improvements were observed, the overall practicality of the system depends on optimizing power consumption and system efficiency.

In conclusion, the experimental results validate the potential of HHO-assisted combustion as an effective supplementary technique for improving fuel efficiency and reducing emissions in small displacement petrol engines. The developed prototype and obtained results provide a strong foundation for further optimization, including advanced control strategies, improved cell design, and integration with alternative energy sources. With continued development, HHO technology can emerge as a promising solution for enhancing the performance and environmental sustainability of commuter motorcycles.

V. FUTURE SCOPE

Although the present work successfully covers the design, fabrication, and integration of an HHO dry cell system for a two-wheeler engine, the experimental validation phase is yet to be completed. Therefore, several future research and development opportunities exist to enhance the technical depth, practical feasibility, and industrial applicability of the system.

5.1 Experimental Performance Validation

The immediate future scope of this project involves conducting controlled experimental testing under various load and speed conditions. Detailed evaluation of the following parameters will provide quantitative validation:

- Brake Thermal Efficiency (BTE)
- Brake Specific Fuel Consumption (BSFC)
- Torque and Brake Power
- Exhaust Emissions (CO, HC, and NO_x)
- Exhaust Gas Temperature

Repeated trials and statistical analysis will improve reliability and accuracy of results.

5.2 Optimization of Electrolyzer Design

Further improvements can be made in:

- Electrode plate configuration (number of plates and spacing)
- Plate surface treatment for improved conductivity
- Advanced electrolyte concentration optimization
- Reduction of internal resistance and heat generation

Improving electrolyzer efficiency will reduce electrical load on the engine and enhance overall system performance.

5.3 Energy Efficiency and Net Power Analysis

A detailed energy balance study can be performed to evaluate:

- Electrical power consumption of HHO generation
- Alternator load impact on engine
- Net fuel savings after considering electrolysis power requirement

This analysis is crucial for determining the real-world practicality of the system.

5.4 Integration with Electronic Control Systems

Future work may include integration with:

- Engine Control Unit (ECU)
- RPM-based automatic HHO flow regulation
- Smart current control using sensors

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Such automation would allow HHO production only during specific load conditions, improving efficiency and safety.

5.5 Long-Term Durability Testing

Extended operational testing can be conducted to study:

- Electrode corrosion behavior
- Electrolyte degradation
- Engine component wear
- Carbon deposit formation

This will help assess long-term reliability and maintenance requirements.

5.6 Application to Different Engine Types

The system can be further tested on:

- Higher cc motorcycles
- Carbureted and fuel-injected engines
- Three-wheelers and small commercial vehicles

Comparative studies across engine types will broaden research applicability.

5.7 Emission Compliance Studies

Future studies may analyze compliance with emission norms such as Bharat Stage VI by conducting certified emission testing. This would determine whether HHO supplementation can contribute to meeting stricter environmental standards.

5.8 Hybrid and Renewable Energy Integration

Another promising direction includes:

- Powering the electrolyzer using solar-assisted charging
- Integrating HHO systems with hybrid vehicles
- Using supercapacitors for stable power supply

This could reduce dependency on engine-generated electrical power.

5.9 Mathematical Modeling and Simulation

Developing combustion models and simulation studies using software such as ANSYS or GT-Power could help:

- Predict combustion behavior with HHO
- Optimize injection rate
- Analyze flame propagation characteristics

Simulation studies would complement experimental findings.

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