“PROTOTYPE OF HYDROGEN COMBUSTION ENGINE”
MECHANICAL ENGINEERING

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KEYWORDS:

Emission reduction, Hydrogen generation, Hydrogen safety, Green fuel and Electrolysis

INTRODUCTION:

The hydrogen combustion engine utilizes hydrogen as fuel in internal combustion engines, offering a cleaner alternative to fossil fuels. It aims to reduce CO_2 emissions while retaining performance and efficiency. This project explores hydrogen’s potential for sustainable power and transportation applications.

- **Background**
  Global energy demand is rising, leading to increased fossil fuel use and CO_2 emissions.This contributes to climate change, air pollution, and resource depletion.Renewable sources are clean but intermittent, creating storage challenges.Hydrogen can store renewable energy efficiently, enabling its use on demand.As a fuel, hydrogen produces only water vapor, making it eco-friendly.
- **Problem Statement**
  Challenges include costly hydrogen production, energy-intensive compression, and safe, efficient storage.Hydrogen storage at 100 bar requires strong yet lightweight tanks.Infrastructure for distribution and end-use needs development.

- **Project Goals**

  Design a system integrating electrolysis, compression, and combustion. Optimize hydrogen generation efficiency and minimize energy losses. Ensure safety and cost-effectiveness in high-pressure storage. Improve combustion systems to reduce NOx emissions.
- **Scope**

  Study electrolyzer types, compression technologies, and high-pressure storage materials.Analyze combustion efficiency and emission control strategies like EGR and SCR.Enhance the overall energy efficiency of the hydrogen cycle.

OBJECTIVES:

1. Develop a hydrogen combustion engine that delivers low emissions comparable to conventional gasoline or diesel engines.
2. Investigate the impact of hydrogen combustion on engine longevity, material degradation, and maintenance requirements.
3. Ensure that the engine design can be integrated with existing hydrogen storage and distribution infrastructure, minimizing additional costs to end-users.
4. Optimize fuel injection, ignition timing, and air-fuel ratios for stable and efficient hydrogen combustion.

METHODOLOGY:

1. **Literature Review**: Study the fundamentals of hydrogen combustion engines (HCE), covering performance, limitations, emissions, and integration challenges.

2. **Hydrogen Production**: Analyze electrolysis-based hydrogen generation, comparing Proton Exchange Membrane (PEM) and Alkaline electrolyzers in terms of efficiency, cost, and energy demand.

3. **Renewable Integration**: Explore the use of solar and wind energy to power electrolyzers, ensuring carbon-free hydrogen production.

4. **Environmental Impact**: Evaluate the carbon footprint and lifecycle emissions of green hydrogen production methods.

5.**Hydrogen Storage Technologies**: Research advanced storage methods including high-pressure (up to 700 bar) and cryogenic systems, focusing on vehicular applications.

6. **Advanced Storage Materials**: Study lightweight, high-strength materials like carbon fiber-reinforced composites for safe and efficient hydrogen tank design.

7. **Combustion Properties**: Understand hydrogen's combustion characteristics (e.g., high diffusivity, wide flammability, fast flame speed) and their impact on engine performance.

8. **Engine Modifications**: Identify technical changes needed for conventional engines to run on hydrogen, including combustion chamber design, ignition timing, and air-fuel control.

9. **Hydrogen Infrastructure**: Assess the practicality of deploying HCE vehicles by reviewing current refueling stations, pipelines, and hydrogen transport systems.

10. **System Development**: Build a small-scale electrolysis and compression system with safety features, using PEM or Alkaline electrolyzers and compressors up to 100 bar.

11. **Engine Testing**: Conduct controlled engine tests to evaluate thermal efficiency, torque, combustion stability, and compare NOx emissions with fossil fuel engines.

12. **Reporting & Analysis**: Document methodology, results, system efficiency, encountered challenges, and propose future improvements or research directions.

RESULTS AND CONCLUSION:

Two Test Scenarios: Emissions were measured from petrol-only combustion and hydrogen-enhanced combustion using a modified carburetor.

1. **Hydrogen Generation**: Produced via electrolysis using renewable energy, yielding high-purity, eco-friendly hydrogen fuel.
2. **Compression Process**: Hydrogen was compressed to ~100 bar using specialized compressors for efficient storage.
3. **High-Pressure Storage**: Stored in carbon-fiber tanks equipped with safety features like pressure relief valves to handle high pressures safely.
4. **Controlled Gas Flow**: Regulated via precision valves to ensure optimal flow and pressure during combustion, preventing backflow and enhancing safety.
5. **Combustion Introduction**: Delivered through an adapted carburetor to ensure proper vaporization and air-fuel mixing for complete combustion.

6. **Emission Metrics Measured**: CO, HC, CO_2, and O_2 levels were compared to evaluate environmental and combustion performance.
7. **CO Reduction**: CO dropped significantly from **2.431% (petrol)** to **0.133% (hydrogen)**, showing near-complete oxidation.
8. **HC Reduction**: Hydrocarbons reduced drastically from **3071 PPM to 269 PPM**, indicating cleaner and more complete combustion.
9. **CO_2 Increase**: CO_2 levels rose from **0.94% to 2.03%**, attributed to more complete combustion and oxidation of residual hydrocarbons.
10. **O_2 Decrease**: Slight drop in O_2 (from 15.35% to 14.69%) suggests improved combustion efficiency with higher oxygen utilization.
11. **Higher Flame Speed**: Hydrogen’s faster flame propagation enhances combustion completeness and reduces unburnt emissions.
12. **Better Air-Fuel Mixing**: Hydrogen’s high diffusivity allows for uniform combustion and fewer rich/lean pockets, improving thermal efficiency.
13. **Low Ignition Energy**: Enables easier combustion initiation, especially under lean conditions, improving fuel economy and performance.
14. **Reduced Engine Knock**: Due to hydrogen's high autoignition temperature, higher compression ratios can be achieved safely.

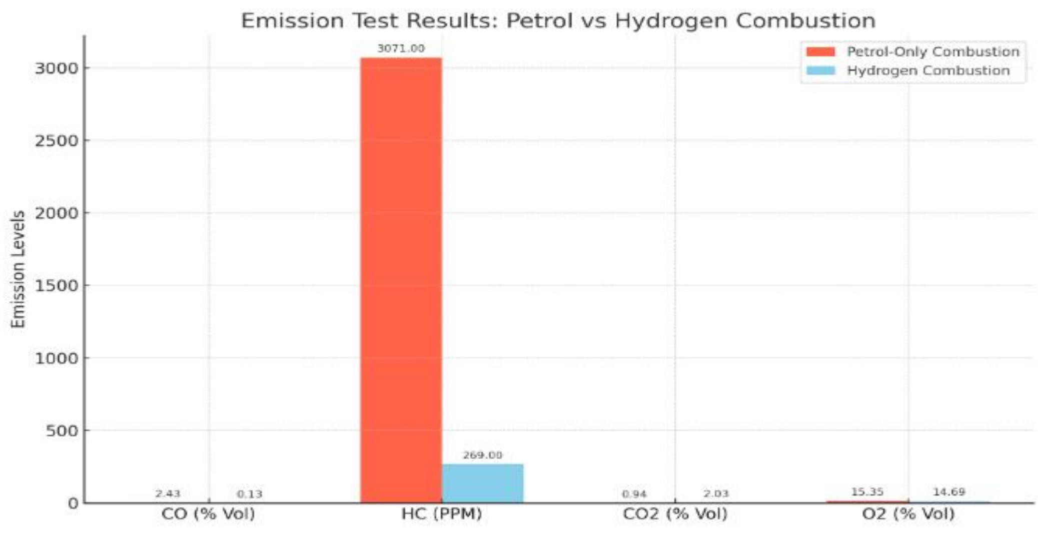

Fig1: Graphical representation of obtained Data

PROJECT OUTCOMES AND INDUSTRY RELEVANCE:

1. **Developed a functional hydrogen combustion engine prototype** that demonstrates a cleaner alternative to petrol, suitable for retrofitting existing IC engines with minimal modifications.
2. **Achieved significant emission reductions**, including over 94% decrease in CO and a drastic drop in HC levels, highlighting hydrogen's potential to meet strict environmental regulations.
3. **Successfully generated and stored hydrogen at 100 bar** using renewable-powered electrolysis, offering a scalable model for green hydrogen integration in automotive applications.
4. **Optimized engine performance** through enhanced combustion efficiency, stable ignition, and lean-burn compatibility, validating hydrogen's role in improving fuel economy and reducing engine knocking.
5. **Designed and implemented a safe hydrogen storage and delivery system**, using high-pressure carbon-fiber tanks and non-return valves—directly applicable to commercial vehicle and infrastructure safety standards.
6. **Provided critical emission and combustion data**, supporting automotive OEMs, research labs, and policy bodies in evaluating hydrogen's viability as a mainstream transportation fuel.
7. **Demonstrated compatibility with current fuel systems and components**, enabling cost-effective adoption in industries without overhauling existing vehicle platforms.
8. **Contributed to the National Hydrogen Roadmap** by aligning with clean fuel mandates and offering technical evidence for hydrogen's role in sustainable mobility.
9. **Laid the foundation for industrial adoption** in sectors such as logistics, public transportation, and agriculture, where clean and efficient alternatives to diesel engines are urgently needed.

10. **Opened pathways for future innovation**, including hybrid fuel systems, direct hydrogen injection, improved storage materials, and enhanced combustion control—paving the way for India's hydrogen economy.

FUTURE SCOPE:

1. **Designed a working hydrogen combustion system prototype using modified IC engine**
   Modified a standard IC engine to use hydrogen as fuel. The engine was tested for performance and efficiency.
2. **Generated hydrogen on-site using renewable-powered electrolysis**
   Hydrogen was produced using renewable energy-driven electrolysis. This ensured sustainable, on-site hydrogen generation.
3. **Achieved stable hydrogen compression to 100 bar for storage**Hydrogen was compressed to 100 bar for efficient storage. This pressure level ensured safe and practical storage.
4. **Developed a safe high-pressure storage tank with integrated relief systems**
   A high-pressure tank was designed for safe hydrogen storage. Integrated relief systems prevent over-pressurization risks.
5. **Integrated hydrogen gas through a customized carburetor system**
   A customized carburetor optimized hydrogen-air mixing. This ensured efficient fuel delivery and combustion in the engine.
6. **Engine ran efficiently on hydrogen with optimized air-fuel mixing**
   The engine ran smoothly on hydrogen after fine-tuning the air-fuel ratio. This improved overall engine efficiency.
7. **Reduced CO emissions by over 94% compared to petrol combustion**
   Hydrogen combustion resulted in a 94% reduction in CO emissions. This significantly improved air quality and environmental impact.
8. **Lowered hydrocarbon (HC) emissions from 3071 PPM to 269 PPM**
   HC emissions were reduced from 3071 PPM to 269 PPM with hydrogen. This demonstrated hydrogen’s cleaner combustion process.
9. **Demonstrated increased combustion efficiency and thermal stability**
   Hydrogen combustion led to better efficiency and more stable thermal performance. This enhanced engine reliability and power output.

10. **Validated use of hydrogen with standard engine components and minor modifications**

    Hydrogen was successfully used with standard engine parts, requiring only minor adjustments. This made the system adaptable to existing engines.

11. **Ensured complete combustion using non-return valves and flow regulators**

    Non-return valves and flow regulators ensured complete hydrogen combustion. These components optimized gas flow and combustion safety.