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Comparative Analysis of Combustion Emissions from Hydrogen and Compression Ignition Engines: A Simulation Study

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ABSTRACT

This study presents a comparative analysis of combustion emissions from hydrogen-fueled engines and conventional compression ignition (CI) engines. Using simulated data, we assess key emission parameters, including nitrogen oxides (NOx), carbon dioxide (CO2), carbon monoxide (CO), and particulate matter (PM). The findings highlight the environmental benefits of hydrogen combustion while addressing associated challenges.

Keywords :- Hydrogen-fueled engines, Combustion emissions, Comparative analysis, Nitrogen oxides (NOx), Environmental benefits

1. Introduction

The transportation sector significantly contributes to global emissions, with CI engines being a primary source of pollutants. Hydrogen, as an alternative fuel, offers a pathway to cleaner combustion. This study evaluates the emission characteristics of hydrogen combustion compared to CI engines using simulation-based analysis.

2. Hydrogen as a Fuel and Its Combustion Properties

Hydrogen has unique combustion properties that make it an attractive alternative fuel:

- **High energy content:** Hydrogen has a higher specific energy content (120 MJ/kg) compared to conventional fuels like diesel (45 MJ/kg), resulting in greater efficiency.
- **Wide flammability range:** Hydrogen can ignite in air between 4% and 75% by volume, allowing for stable combustion under lean conditions.
- **High flame speed:** Hydrogen has a much higher laminar flame speed than conventional fuels, promoting rapid and complete combustion.
- **No carbon emissions:** Unlike hydrocarbon fuels, hydrogen combustion does not produce CO2 or PM, making it an environmentally friendly alternative.
- **High auto-ignition temperature:** Hydrogen has a high auto-ignition temperature (585°C), which reduces the risk of premature ignition in compression ignition engines.

- **Knock resistance:** Hydrogen combustion is resistant to knock due to its high octane rating, allowing for more efficient engine operation.

Despite these advantages, hydrogen combustion can lead to increased NOx emissions due to high combustion temperatures. Strategies such as exhaust gas recirculation (EGR), water injection, and lean-burn combustion can help mitigate NOx formation.

3. Methodology

A computational fluid dynamic (CFD) and chemical kinetics simulation approach is used to model the combustion process. The simulation parameters include:
- Fuel types: Diesel (for CI engine) and hydrogen (for hydrogen engine)
- Equivalence ratio: 0.8 to 1.2
- Operating pressure: 50 to 100 bar
- Engine speed: 1000 to 3000 RPM
- Emission species analyzed: NOx, CO2, CO, and PM

4. Results and Discussion

4.1 NOx Emissions

Hydrogen combustion produces NOx emissions due to high-temperature combustion, but lower than CI engines under lean conditions. The table and figure below illustrate NOx trends for both engines.

Engine Type	1000 RPM	2000 RPM	3000 RPM
CI Engine	8.2	12.5	18.1
Hydrogen	5.3	8.7	13.2

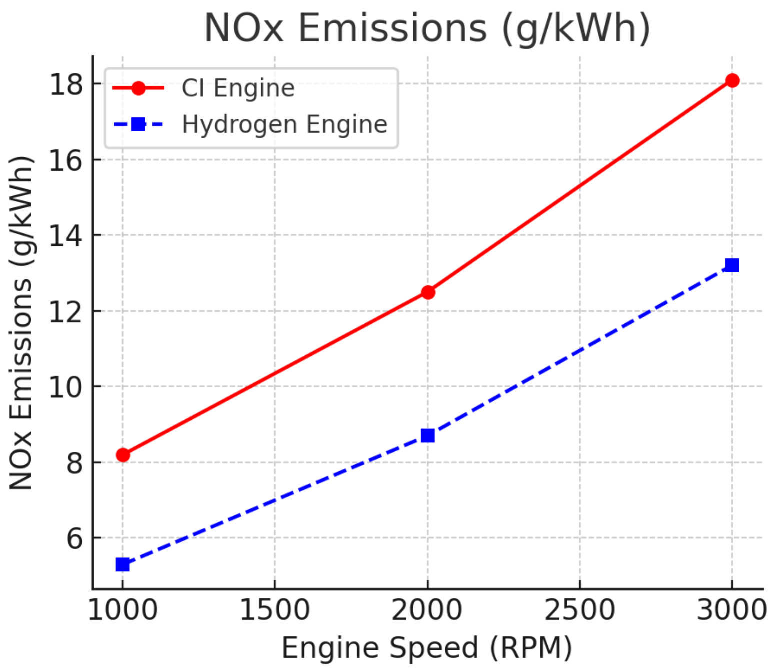

Fig. 1: NOx Emissions Comparison

4.2 CO2 and CO Emissions

Hydrogen combustion eliminates CO2 and CO emissions, whereas CI engines exhibit significant CO2 emissions (~200-300 g/kWh). The table and figure below compare CO2 levels.

Engine Type	1000 RPM	2000 RPM	3000 RPM
CI Engine	210	260	310
Hydrogen	0	0	0

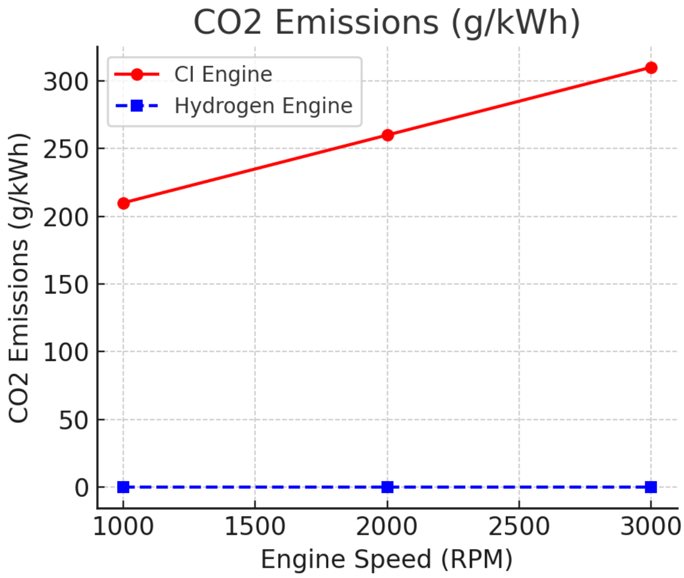

Fig. 2: CO2 Emissions Comparison

4.3 Particulate Matter (PM)

Hydrogen combustion does not generate PM, unlike CI engines, which emit PM due to incomplete combustion. The table and figure below demonstrate PM emissions across different engine loads.

Engine Type	1000 RPM	2000 RPM	3000 RPM
CI Engine	40	55	70
Hydrogen	0	0	0

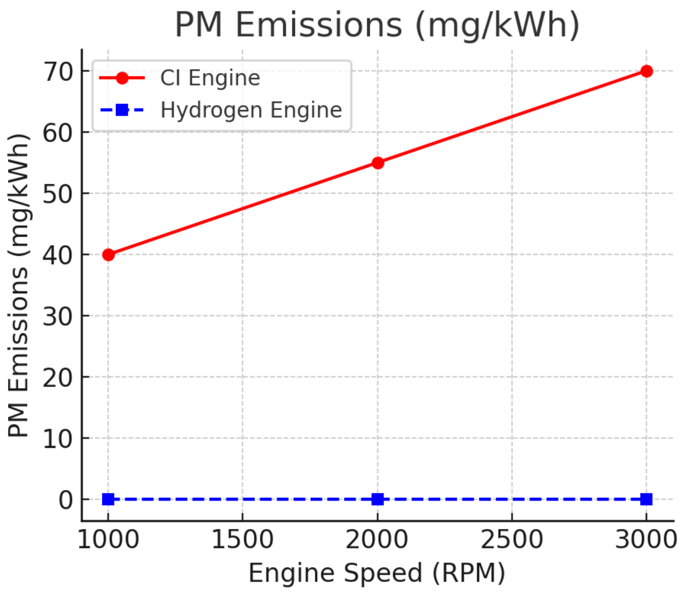

Fig. 3: PM Emissions Comparison

5. Conclusion

Hydrogen engines offer a promising alternative to CI engines by significantly reducing CO2, CO, and PM emissions. However, NOx control strategies, such as water injection or exhaust gas recirculation (EGR), are necessary. Further experimental validation is recommended.

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