"PERFORMANCE ANALYSIS OF SINGLE CYLINDER FOUR STROKE CI ENGINE USING HYDROGEN SUPPLEMENTATION"

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Abstract: Hydrogen supplementation in internal combustion engines, particularly in compression ignition (CI) engines, has emerged as a promising approach to enhance performance and minimize the environmental impact of traditional diesel engines. Hydrogen, being a renewable and clean-burning fuel, boasts properties such as a high flame speed, zero carbon content, and a wide range of flammability, making it an ideal candidate for improving the combustion process in CI engines. When hydrogen is introduced as a secondary fuel, it mixes with air and participates in the combustion process, leading to a more complete burn of the diesel fuel, thereby increasing the thermal efficiency of the engine and reducing harmful emissions like carbon dioxide (CO_2), carbon monoxide (CO), and particulate matter (PM).

The inclusion of hydrogen in CI engines can also reduce dependency on diesel fuel, promoting energy diversification and reducing greenhouse gas emissions. However, its implementation poses challenges, such as higher combustion temperatures that may lead to

increased nitrogen oxide (NOx) emissions, as well as the need for specialized storage and handling systems to ensure safety due to hydrogen's highly flammable nature. Moreover, the optimal hydrogen-diesel ratio is critical, as excessive hydrogen can lead to abnormal combustion phenomena, such as pre-ignition and knocking.

This study investigates the performance characteristics of a single-cylinder four-stroke CI engine supplemented with hydrogen. Key performance metrics, such as brake thermal efficiency (BTE), specific fuel consumption (SFC), and emissions, are evaluated across various operating conditions and hydrogen-diesel mixtures. The results aim to provide a comprehensive understanding of how hydrogen supplementation can improve engine efficiency while addressing environmental concerns, making it a viable step toward sustainable and cleaner transportation solutions.

1. Limitations of current fuel practices in Gasoline engines

The fuel which is used worldwide at present is Petrol and diesel which is the fossile fuel. As it is said that all fossile fuels like crude oil, coal, etc. has limited availability so in order to conserve them there are some alternatives like LPG, CNG, producer gas, biogas, etc. gaseous fuels which are available at rates less than Petrol. The emissions like CO, CO_2, Hydro Carbons by using Petrol/Gasoline as fuel are very high which will result into the effects like green-house effect, melting of Glaciers, global warming and so on. Our country is importing almost 90 percent of crude oil from OPEC countries. So, we have to pay them a lot out of our Countries net income. So, by considering this scenario, it is better to go for the use of Hydrogen as fuel in present Petrol and diesel engines with little modification in fuel supply system.

2.Methodology

The methodology for using hydrogen as a supplementary fuel in a four-stroke compression ignition (CI) engine involves a systematic approach to integrate hydrogen into the combustion process, improve efficiency, and reduce emissions. First, a suitable CI engine is selected and equipped with a hydrogen supply system, which includes storage (typically compressed hydrogen tanks) and an injection mechanism to introduce hydrogen into the intake manifold or directly into the combustion chamber. Diesel acts as the primary fuel to initiate ignition, while hydrogen serves as a secondary fuel to enhance the combustion process due to its high flammability and energy content.

The air-fuel mixture is carefully managed, and ignition timing is optimized to prevent issues such as knocking or pre-ignition. Engine performance is then tested under varying conditions to measure parameters like thermal efficiency, specific fuel consumption, and power output. Emissions are analyzed using exhaust gas analyzers to assess reductions in pollutants such as CO_2, CO, NOx, and unburned hydrocarbons. Safety measures are implemented throughout the process, including flame arresters and leak detection systems to handle hydrogen's reactive nature. Data collected from these tests is used to refine hydrogen-to-diesel ratios, ensuring a balance between performance and emissions while evaluating the economic and technical feasibility of the approach. This method demonstrates a practical pathway for integrating hydrogen into CI engines, paving the way for cleaner and more efficient fuel use.

3.Requirements for Converting Existing Engines to Hydrogen Supplementation Engines

Converting a conventional diesel engine into a hydrogen-supplemented engine involves several modifications and additional components to ensure safe and efficient operation. These changes address the differences in hydrogen's properties compared to traditional fuels and aim to optimize the dual-fuel combustion process.

Key Requirements:

1. Hydrogen Supply and Injection System:

- High-Pressure Storage: A hydrogen storage tank with safety features and appropriate pressure ratings (usually 350–700 bar) is required.
- Injection System: Hydrogen injectors or a port injection system to introduce hydrogen into the intake manifold or directly into the combustion chamber.
- Pressure Regulators: To control the flow rate and pressure of hydrogen for consistent and safe delivery.

2. Engine Control Modifications:

- Advanced ECU (Engine Control Unit): Required to precisely manage the injection timing and quantities of both hydrogen and diesel.
- Knock Control System: To prevent knocking due to hydrogen's low ignition energy and high flame speed.
- Lambda Sensors: To monitor the air-fuel ratio and ensure optimal combustion.

3. Air Intake System:

- Enhanced Turbocharging (if applicable): To manage the increased volume of intake air and hydrogen mixture.
- Intercoolers: To prevent pre-ignition by cooling the hydrogen-air mixture.

4. Ignition System Adjustments:

- Pilot Diesel Injection: Diesel fuel must be injected in small quantities to act as a pilot fuel for initiating hydrogen combustion.

- Injection Timing Optimization: Advanced timing to synchronize the ignition of diesel and hydrogen for smooth combustion.

5. Exhaust and Emission Control:

- NOx Control Technologies: Systems such as Exhaust Gas Recirculation (EGR) or Selective Catalytic Reduction (SCR) to mitigate NOx emissions from high combustion temperatures.
- Particulate Filters (Optional): To address any residual soot from diesel combustion.

6. Safety Features:

- Flame Arrestors: Installed in the hydrogen supply line to prevent flashbacks.
- Leak Detectors: Hydrogen sensors to detect leaks due to hydrogen's high diffusivity.
- Pressure Relief Valves: To ensure safe operation of the hydrogen storage system.

7. Material Compatibility:

- Hydrogen-Compatible Components: Certain engine materials may need to be replaced to prevent hydrogen embrittlement, particularly in fuel lines and storage systems.

8. Calibration and Tuning:

- Fine-tuning of the engine's fuel maps and control parameters to balance efficiency, power output, and emissions.

3.4 Characteristics comparison of Diesel and Hydrogen

Properties of Diesel and Hydrogen

Property	**Diesel**	**Hydrogen**
Chemical Composition	Hydrocarbons (C_nH_m)	H_2 (pure molecular hydrogen)
State	Liquid at ambient temperature and pressure	Gas at ambient temperature and pressure
Density	~850 kg/m³	~0.0899 kg/m³ (at STP)
Energy Content (by weight)	45.5 MJ/kg	120 MJ/kg
Energy Content (by volume)	High (dense liquid fuel)	Low (compressed or liquefied gas)
Flammability Range (in air)	0.6–5% by volume	4–75% by volume

Property	**Diesel**	**Hydrogen**
Auto-Ignition Temperature	210–280°C	500–585°C
Stoichiometric Air-Fuel Ratio	~14.6:1	~34.3:1
Flame Speed	Slow	Very high
Ignition Energy	High	Very low
Combustion Products	CO_2, water, NOx, particulates	Water vapor, trace NOx
Boiling Point	~150–370°C (complex mixture)	-253°C (for liquid hydrogen)
Renewability	Non-renewable (fossil-based)	Renewable (e.g., from electrolysis)
Storage	Stored as a liquid in tanks	Stored as compressed gas or liquid
Emission Profile	High CO_2, particulates, NOx	Zero CO_2, no particulates, minimal NOx
Toxicity	Low (relatively safe for handling)	Non-toxic, but flammable
Safety Concerns	Moderate (less flammable)	High (highly flammable and diffusive)
Carbon Content	High	Zero
Cost (current)	Relatively affordable	Expensive due to production and storage

4.2 The Experimental Set-Up CRDI VCR Engine Test Setup (Computerized)

The setup consists of single cylinder, four stroke, Diesel engine connected to eddy current type dynamometer for loading. It is provided with necessary instruments for combustion pressure and crank-angle measurements. These signals are interfaced to computer through engine indicator for Pθ−PV diagrams. Provision is also made for interfacing airflow, fuel flow, temperatures and load measurement. The set up has stand-alone panel box consisting of air box, fuel tank, manometer, fuel measuring unit, transmitters for air and fuel flow measurements, process indicator and engine indicator. Rotameters are provided for cooling water and calorimeter water flow measurement.

The setup enables study of engine performance for brake power, indicated power, frictional power, BMEP, IMEP, brake thermal efficiency, indicated thermal efficiency, Mechanical efficiency, volumetric efficiency, specific fuel consumption, A/F ratio and heat balance. Labview based Engine Performance Analysis software package “Enginesoft” is provided for on line performance evaluation.

RESULTS AND DISCUSSION

1) **100% diesel (0% Hyd & 100% Diesel)**
   Discussion- Diesel operation, our results demonstrate the typical performance characteristics of a diesel engine under varying loads. As the load increases, power output and efficiencies generally improve, while specific fuel consumption decreases.

Sr. No	Load	BP (KW)	IP (KW)	FP (KW)	BMEP (bar)	IMEP (bar)	η_{ITH} (%)	η_{BTH} (%)	η_{mec} (%)	η_{Vol} (%)	BSFC (Kg/kWh)	ISFC (Kg/kWh)
1	0	00.00	03.89	03.89	00.00	04.67	83.66	00.00	00.00	00.00	00.00	00.26
2	3	00.87	05.20	04.33	01.04	06.24	81.31	13.54	16.66	67.48	01.17	00.20
3	6	01.74	05.42	03.68	02.09	06.51	54.68	17.65	32.15	67.83	00.59	00.19
4	9	02.56	06.18	03.62	03.08	07.42	62.59	25.93	41.44	66.44	00.40	00.16
5	12	03.44	07.04	03.56	04.18	08.50	58.87	28.93	49.14	67.05	00.30	00.15

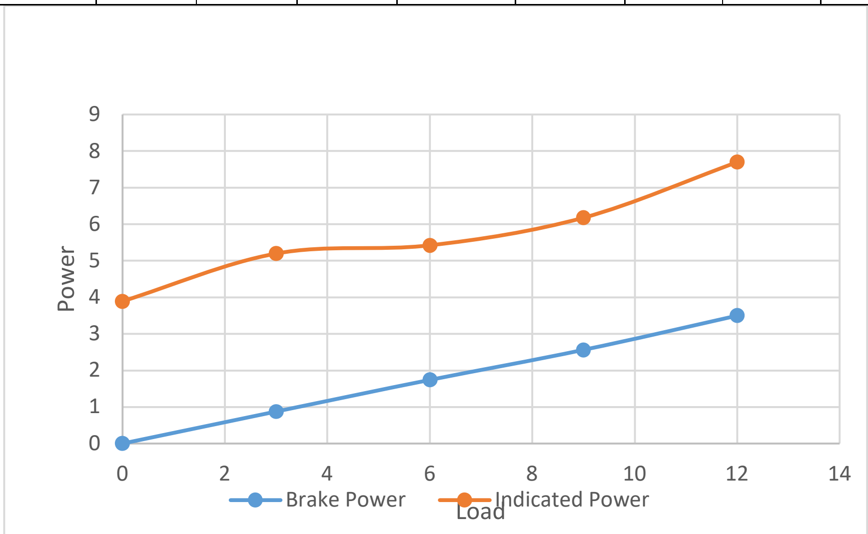

Table 6.1 Load vs Power (100% Diesel)

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