IJARSCT

ISSN (Online) 2581-9429

International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)

International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal

Impact Factor: 7.53

Volume 4, Issue 7, May 2024

Hydrogen Internal Combustion Engine Vehicle

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Abstract: *The need to decarbonize transportation is becoming more urgent, which has increased interest in essential energies like hydrogen. Hydrogen internal combustion engine vehicles (HICEVs) present a potentially reciprocal strategy, although hydrogen energy cell vehicles (FCEVs) have received a lot of attention. This essay offers a critical analysis of HICEV technology as it exists today, highlighting its potential, difficulties, and role in the transition to sustainable mobility. We start by describing the fundamental ideas behind HICEVs and stressing the similarities and contrasts with gasoline-powered vehicles. We also delve into the environmental advantages of HICEVs, highlighting their almost zero tailpipe emissions and implied carbon neutrality based on the types of hydrogen products they produce. However, we also acknowledge that HICEVs have drawbacks, such as reduced efficiency when compared to FCEVs, more complex engineering, and logistical difficulties with hydrogen.*

Keywords: Hydrogen, Internal Combustion Engine, HICEV, FCEV, Sustainable Transportation, Decarbonization, Emissions, Engine Efficiency, Hydrogen Infrastructure

I. INTRODUCTION

A hydrogen internal combustion machine vehicle (HICEV) is a type of hydrogen vehicle using an internal combustion machine. Hydrogen internal combustion machine vehicles are different from hydrogen energy cell vehicles (which use hydrogen electrochemically rather than through combustion). rather, the hydrogen internal combustion machine is simply a modified interpretation of the traditional gasoline- powered internal combustion machine. The absence of carbon means that no CO2 is produced, which eliminates the main hothouse gas emigration of a conventional petroleum machine. As pure hydrogen doesn't contain carbon, there are no carbon- grounded adulterants, similar as carbon monoxide (CO) or hydrocarbons (HC), nor is there any carbon dioxide (CO2) in the exhaust. As hydrogen combustion occurs in an atmosphere containing nitrogen and oxygen, it can still produce oxides of nitrogen known as NOx. In this way, the combustion process is important like other high temperature combustion energies, similar as kerosene, gasoline, diesel, or natural gas. Thus, hydrogen combustion machines aren't considered zero emigration. A strike is that hydrogen is delicate to handle. Due to the veritably small size of the hydrogen patch, hydrogen is suitable to blunder through numerous supposedly solid accoutrements in a process called hydrogen embrittlement.

Escaped hydrogen gas mixed with air is potentially explosive.

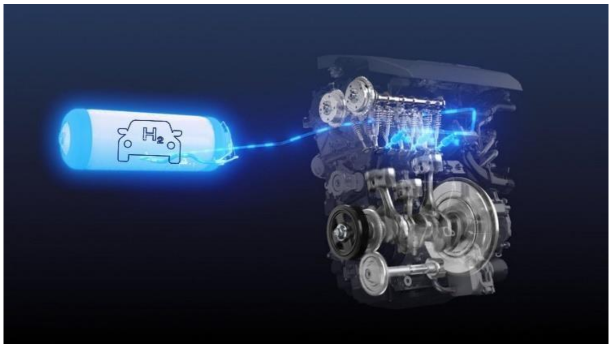

Figure 1. Hydrogen IC Engine

DOI: 10.48175/IJARSCT-18786

II. COMBUSTIVE PROPERTIES OF HYDROGEN

Properties contribute to its use as a combustible fuel are:

- Wide range of flammability
- Low ignition energy
- Small quenching distance
- High autoignition Temperature
- High flame speed at stoichiometric ratios
- High diffusivity
- Very low density

III. AIR-FUEL RATIO

Combustion ratio of hydrogen in air is about 34:1 by mass, which is much higher than the 14.7:1 A/F of gasoline.

Since hydrogen is a gaseous energy at ambient conditions it displaces further of the combustion chamber than a liquid energy. Accordingly, the lower part of the combustion chamber can be enthralled by air. At stoichiometric conditions, hydrogen displaces about 30% of the combustion chambers, compared to about 1 to 2 for gasoline. Figure 2 compares combustion chamber volumes and energy content for gasoline and hydrogen fueled engines. Depending on the method used to meter the hydrogen to the engine, the power output compared to a gasoline engine can be anywhere from 85% (intake manifold injection) to 120% (high pressure injection).

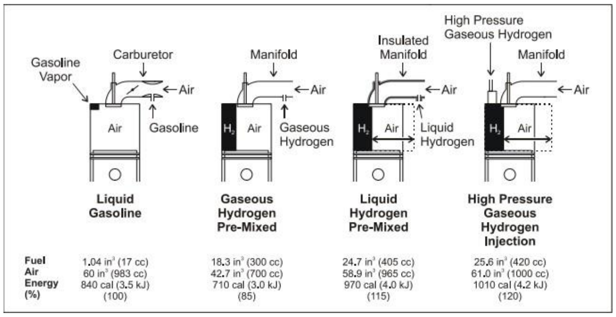

Figure 2 comparison of Gasoline with Hydrogen

IV. EMISSION

The combustion of hydrogen with oxygen produces water as its only product:

$$2H2 + O2 = 2H2O$$

The combustion of hydrogen with air however can also produce oxides of nitrogen (NOx):

$$H2 + O2 + N2 = H2O + N2 + NOx$$

NOx (nitrogen oxides) is produced because of elevated temperatures within the combustion chamber during the combustion process. The heightened temperature induces a reaction wherein nitrogen from the surrounding air combines with oxygen. The quantity of NOx generated is contingent upon:

- the air/fuel ratio
- the engine compression ratio
- the engine speeds
- the ignition timing
- whether thermal dilution is utilized

Apart from nitrogen oxides, small amounts of carbon monoxide and carbon dioxide may be found in the exhaust gas, stemming from the combustion of leaked oil in the combustion chamber. The emissions vary based on the engine's condition, particularly the burning of oil, and the chosen operating strategy, which can range from a rich to a lean air/fuel ratio. In the case of a hydrogen engine, emissions can range from nearly zero (as low as a few parts per million) to elevated levels of NOx and notable carbon monoxide emissions.

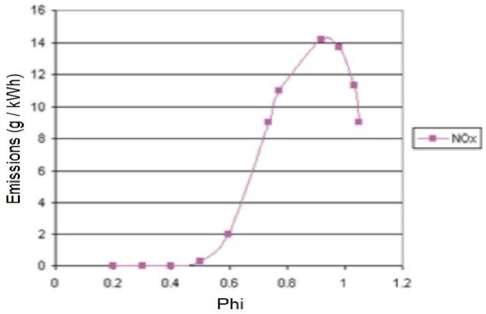

Figure 3: Emission graph of hydrogen

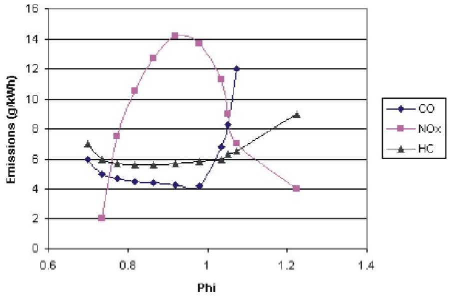

Figure 4. Emission graph of gasoline

V. POWER OUTPUT

The stoichiometric air/fuel ratio for hydrogen is 34:1, leading to hydrogen displacing 29% of the combustion chamber at this ratio, leaving only 71% for air. This results in a lower energy content compared to gasoline, which, being a liquid, occupies a smaller volume and allows more air to enter the combustion chamber. Carbureted and port injection methods mix fuel and air before entering the combustion chamber, limiting the maximum theoretical power to around 85% of gasoline engines. In contrast, direct injection systems, which mix fuel with air after the intake valve closes (achieving 100% air in the combustion chamber), can yield approximately 15% higher output than gasoline engines. The choice of fuel metering influences the maximum output of a hydrogen engine, making it either 15% higher or lower than gasoline when using a stoichiometric air/fuel ratio. However, due to the high combustion temperature and the consequent formation of nitrogen oxides (NOx) at stoichiometric ratios, hydrogen engines are not typically designed for this condition. Hydrogen engines are commonly designed to use about twice the theoretically required air for complete combustion, significantly reducing NOx formation to near zero. Unfortunately, this adjustment also reduces power output to roughly half that of a similarly sized gasoline engine. To compensate for this power loss, hydrogen engines are often larger than gasoline engines or equipped with turbochargers or superchargers.

VI. LITERATURE REVIEW

An overview is given of the design features in which a dedicated hydrogen engine differs from traditionally fuelled engines, following Verhelst (2005)

Abnormal Combustion

Overcoming abnormal combustion in hydrogen-powered engines poses a significant challenge, and the strategies employed to prevent such occurrences have profound implications for engine design, mixture formation, and load control. In the case Theark-ignition engines, three distinct abnormal combustion regimes are recognized: knock (auto-ignition of the end gas region), pre-ignition (uncontrolled ignition triggered by a hot spot, preceding the spark ignition), and backfire (alternatively termed backflash, flashback, or induction ignition, signifying premature ignition during the intake stroke—an early manifestation of pre-ignition).The persistent issue of backfire has been a formidable hurdle in the advancement of hydrogen engines. Various factors have been attributed to the occurrence of backfire, including:

Hot spots within the combustion chamber can be attributed to various factors such as deposits and particulates, as studied by Bardon and Haycock (2002) and MacCarley (1981). The condition of the spark plug is another crucial aspect, with insights provided by Das (2002) and Lucas and Morris (1980). Residual gas, a significant consideration, has been explored by Das (1996), Lucas and Morris (1980), and Berckmüller et al. (2003). Examination of exhaust valves involves research by Berckmüller et al. (2003), Stockhausen et al. (2002), Swain et al. (1988), and TÜV Rheinland (1990), among others.

Energy remaining in the ignition circuit, as discussed by Lucas and Morris (1980) and Kondo et al. (1997).

Ignition cable induction - MacCarley (1981)

Continued combustion within the piston top land area until the moment of inlet valve opening, initiating ignition for the incoming fresh charge - as discussed by Lucas and Morris (1980), Swain et al. (1996), Koyanagi et al. (1994), and Lee et al. (2000).

Pre-ignition phenomena have been explored by various researchers, including Tang et al. (2002), MacCarley (1981), Swain et al. (1988), Koyanagi et al. (1994), and Lee et al. (1995).

Backfire may occur due to the listed factors, and it is imperative for the design of a hydrogen engine to mitigate these issues. This is crucial because deviations from typical engine operation conditions can always be a potential concern.

Air-Fuel Mixture formation

Various approaches to mixture formation have been explored for hydrogen engines, primarily with the aim of achieving operation without the risk of backfire.

External mixture formation using a gas carburetor has been discussed by Lucas and Morris (1980) as well as Jing-Ding et al. (1986).

External mixture formation using "parallel induction" involves a method to postpone the introduction of hydrogen. This can be achieved through a fuel line closure controlled by a distinct valve positioned atop the intake valve. The separate valve opens only when the intake valve has sufficiently lifted, as described by Olavson et al. in 1984.

External mixture formation using a gas carburetor and water injection has been explored, as documented by TÜV Rheinland in 1990 and the works of Binder and Withalm in 1982. In certain instances, this approach is supplemented by the incorporation of exhaust gas recirculation (EGR), as discussed by Davidson et al. in 1986.

Utilizing external mixture formation through timed manifold or port fuel injection (PFI) has been explored in various studies, such as those conducted by Tang et al. (2002), MacCarley (1981), Berckmüller et al. (2003), Swain et al. (1996), Lee et al. (1995), Natkin et al. (2003), and Heffel et al. (1998). Additionally, some investigations have incorporated the concept of 'parallel induction,' as discussed by Heffel et al. (2001).

Formation of internal mixture via direct injection (DI) – Meier et al. (1994), Furuhama (1997), Guo et al. (1999), Kim et al. (1995)

Over the past decade, exclusive utilization of timed port injection and direct injection (occurring either during the compression stroke or later) has been observed, as alternative methods are deemed less adaptable and manageable. Demonstrations have showcased that external mixture formation through port fuel injection yields superior engine efficiencies, prolonged lean operation, reduced cyclic variation, and diminished NOx production compared to direct injection, as evidenced by studies conducted by Smith et al. (1995) and Yi et al. (2000). An inherent advantage of direct injection over port fuel injection lies in its inherent prevention of backfire, contributing to increased maximum power output by allowing the use of richer mixtures without the apprehension of backfire incidents.

Load control strategies

Hydrogen stands out as an exceptionally adaptable fuel in terms of load control, owing to its high flame speeds and broad flammability limits, allowing for efficient operation with lean mixtures and significant dilution. Load control strategies primarily revolve around optimizing engine efficiency and managing NOx emissions. While constant equivalence ratio throttled operation has been showcased in demonstrations, it often incurs a notable power output penalty. Wide open throttle (WOT) operation is preferred whenever possible, taking advantage of increased engine efficiency and avoiding pumping losses. Load regulation through mixture richness (qualitative control) is favored over volumetric efficiency (quantitative control) to enhance overall efficiency. Throughout the engine's load range, diverse strategies leverage the unique properties of hydrogen-air mixtures. NOx production is closely tied to mixture richness, represented by the air-to-fuel equivalence ratio (λ), which controls the maximum combustion temperature. A 'NOx formation limit' is identified at a certain λ, typically around 2, below which NOx production remains low. Below this limit, quality-based mixture control is employed. For idle and very low loads, a lean mixture with WOT ($\lambda > 4$) is used, albeit resulting in a higher coefficient of variation for imep (COV) due to lower combustion velocity and stability. Throttle control is applied at these loads to enrich the mixture. Remarkably high efficiencies exceeding 40% have been reported in this operational range. At high loads beyond the NOx formation limit, throttled stoichiometric operation with a reduction catalyst can be implemented, as demonstrated by BMW. The catalyst's efficiency (>99.5%) is enhanced by the presence of H2 in the exhaust feed gas at $\lambda = 1$, serving as a highly efficient reducing

agent. Alternatively, for increased efficiency, exhaust gas recirculation (EGR) in the range of 0-50% can be utilized instead of throttling to control the quantity of fresh air in the engine, as reported by Ford. Efficiencies of 35% and 40% have been documented for throttle and exhaust gas recirculation (EGR) control, respectively, within this load range. When the engine is under charge for loads surpassing the naturally aspirated full load limit, effective control can be achieved by regulating the charge pressure while maintaining a stoichiometric mixture.

An alternative approach, suggested by BMW, involves employing common port injection for low and part loads, and direct injection for higher loads. This strategy, outlined by Rottengruber et al. (2004), capitalizes on external mixture formation, providing improved mixing and reduced throttling requirements attributable to lower volumetric efficiency. The external mixture formation proves advantageous due to superior mixture preparation and reduced need for throttling. Notably, NOx emissions below 1 ppm have been reported when utilizing a standard three-way catalyst in stoichiometric operation, as demonstrated by Natkin et al. (2003).

VII. CONCLUSION

In conclusion, the research on hydrogen internal combustion engines, focusing on design features and performance comparisons, highlights their potential for sustainable transportation. The emphasis on timed port and direct injection, as opposed to less flexible methods, underscores the importance of adaptability in optimizing engine performance. Studies by Smith et al. (1995) and Yi et al. (2000) show that external mixture formation through port fuel injection offers advantages, including improved efficiencies and reduced emissions, compared to direct injection. The inherent safety benefits of direct injection, preventing backfire and allowing the use of richer mixtures, enhance its appeal for maximizing power output. Looking forward hydrogen internal combustion engines could play a significant role in addressing environmental concerns, with ongoing exploration and development expected to contribute to cleaner and more efficient transportation. Despite existing challenges, the progress made in understanding and refining these engines forms a promising foundation for future advancements in eco-friendly automotive solutions.

REFERENCES

[1]. Aceves S.M. and Smith J.R.: Hybrid and conventional hydrogen engine vehicles that meet EZEV emissions SAE, paper nr 970290, (1997).
[2]. Bardon M.F. and Haycock R.G.: The hydrogen research of R.O. King, Proceedings, 14th World Hydrogen Energy Conference, invited paper, Montreal, Canada, (2002).
[3]. Berckmüller M. et al.: Potentials of a charged SI-hydrogen engine. SAE, paper nr 2003-01-3210, (2003).

DOI: 10.48175/IJARSCT-18786