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Hydrogen-Enriched Gasoline Combustion in Spark-Ignition Engines: Brake Efficiency, Fuel Economy and Combustion Assessment

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ABSTRACT

This manuscript evaluates the performance implications of hydrogen supplementation in gasoline spark-ignition engines, focusing on brake thermal efficiency, gasoline-specific fuel consumption, total fuel-energy accounting and combustion stability. The analysis is based on the submitted M.Tech dissertation and selected published literature. The dissertation describes a comparative engine-test framework and qualitative trends but contains placeholder entries in key numerical results tables. Therefore, no experimental magnitudes, significance levels or optimum blend percentages are invented. The paper develops a transparent interpretation of the mechanisms, identifies required measurement and normalization procedures, and sets out a reproducible path toward a quantified journal submission. The central conclusion is that hydrogen enrichment should be evaluated as a coupled combustion, fuel-energy and operating-condition problem rather than through a single performance or emissions indicator.

Keywords: hydrogen enrichment; spark ignition engine; brake thermal efficiency; specific energy consumption; combustion stability

1. Introduction

The continuing relevance of spark-ignition engines makes incremental decarbonization an important engineering problem. Hydrogen supplementation is a particularly interesting transitional pathway because it changes the fuel chemistry without requiring an entirely new prime mover. Its fast flame development, wide flammability limits and high mass-specific heating value create opportunities for more stable combustion, but the response of an operating engine is controlled by the complete air–fuel system rather than by a fuel property alone. [1], [6].

The underlying dissertation examines gasoline operation and hydrogen-enriched operation over engine-load conditions, with attention to brake power, brake thermal efficiency, brake specific fuel consumption, combustion characteristics and exhaust constituents. The present manuscript isolates one question from that broader investigation. The source dissertation supplies a qualitative comparative interpretation, procedural descriptions and templates for measurements; several displayed results tables contain placeholders rather than numerical observations. Accordingly, this article does not claim numerical improvements, significance tests or experimentally determined optimum settings that cannot be independently recovered from the submitted material. [2], [7].

A central analytical distinction is between replacing gasoline and improving total conversion efficiency. Adding hydrogen can lower gasoline mass flow while supplying extra chemical energy. A lower gasoline-only specific consumption therefore does not, on its own, demonstrate that the engine converts the combined fuel input more efficiently. Proper comparison requires consistent load, speed, mixture strength and ignition strategy, as well as an energy-based denominator that includes both fuels. [3], [8].

The contribution is a source-grounded synthesis of the dissertation methodology and the implications of the reported trends, connected to established hydrogen engine literature. This framework identifies what the available evidence can support and which measurements are necessary to convert qualitative observations into a fully quantified experimental article. [4], [9].

2. Literature Review

Hydrogen-assisted spark ignition has been investigated in both gasoline and gaseous-fuel engines. Fundamental studies explain why hydrogen can accelerate flame-kernel growth and broaden stable lean operation. Research on low-load and lean gasoline engines highlights the importance of mixture preparation, spark timing and operating point. Results from hydrogen-enriched natural-gas engines reinforce the potential for lower cycle-to-cycle variation, but those findings cannot automatically be transferred quantitatively to a gasoline engine. [5], [10].

Hydrogen introduction changes more than a single combustion variable. The intake-fuel delivery architecture affects volumetric efficiency; the hydrogen energy fraction affects fuel displacement; and changes in equivalence ratio alter both flame temperature and oxidation completeness. A comparison that changes several of these variables simultaneously is useful for engineering screening but is less able to attribute a performance difference to hydrogen chemistry alone. [6], [11].

The literature also distinguishes direct hydrogen engines from enrichment of carbon-containing fuels. A hydrogen-only engine may have no fuel-derived carbon at the tailpipe, whereas a gasoline–hydrogen engine continues to emit carbon-bearing products. Likewise, the environmental merit of hydrogen supplementation depends on the upstream production route, an issue separate from brake performance and engine-out emissions. [7], [12].

Reviews of hydrogen internal-combustion engines emphasize trade-offs: increased combustion speed can enhance useful work extraction, yet overly advanced pressure development, thermal loading, pre-ignition and backfire may narrow the usable operating window. Consequently, optimization should be defined as a constrained multi-response problem rather than a search for the maximum hydrogen fraction. [8], [13].

An additional consideration for literature review is reproducibility across operating points. Hydrogen introduction changes more than a single combustion variable. The intake-fuel delivery architecture affects volumetric efficiency; the hydrogen energy fraction affects fuel displacement; and changes in equivalence ratio alter both flame temperature and oxidation completeness. A comparison that changes several of these variables simultaneously is useful for engineering screening but is less able to attribute a performance difference to hydrogen chemistry alone. The governing comparison must retain consistent definitions and units. In particular, a physical mechanism supported by prior work should be identified as mechanistic interpretation until the actual observations and associated uncertainty are available. The distinction between a measured trend, a predicted direction and a literature-supported possibility is essential for transparent engineering reporting. The performance analysis should also distinguish the fraction of gasoline displaced from a true increase in total brake-energy conversion efficiency. [10].

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3. Materials and Methodology

The dissertation describes a comparative engine-testing framework with gasoline as the baseline and multiple hydrogen-enrichment conditions evaluated over a sequence of engine loads. It includes sections on the test engine, fuel preparation, hydrogen delivery, measurement instruments, emissions analysis and statistical validation. The available thesis text does not establish a complete machine-readable raw dataset from which all performance and emission curves could be reconstructed. [9], [14].

For each operating point, the required minimum record consists of engine speed, brake torque, brake power, gasoline mass-flow rate, hydrogen mass-flow rate, lower heating values, intake conditions, mixture equivalence ratio and ignition timing. A meaningful repeatability assessment also records replicate readings and instrument calibration or uncertainty. These fields should be preserved in the final publication dataset rather than inferred from plots or generic expected trends. [10], [15].

Brake power is calculated from torque and angular velocity. Brake thermal efficiency is the ratio of brake power to the total chemical-energy input rate. Gasoline brake-specific fuel consumption is gasoline mass-flow rate divided by brake power, whereas brake-specific energy consumption uses the combined heating-value input from gasoline and hydrogen. These quantities are not interchangeable; using both prevents a reduction in gasoline use from being misreported as an increase in overall thermodynamic efficiency. [11], [16].

The dissertation describes three repeated observations at a common operating point, averaging, standard deviation and combined uncertainty. Those methods are appropriate in principle, but their numerical application requires replicate-level data and instrument uncertainties. Without these observations, this paper restricts itself to directional interpretation, conceptual figures and an explicit validation protocol rather than fabricated confidence intervals or hypothesis-test outcomes. [12], [17].

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4. Results and Discussion

The dissertation discusses a tendency for controlled hydrogen enrichment to improve brake thermal efficiency through faster and more stable combustion. This interpretation is mechanistically plausible: hydrogen can reduce ignition delay and allow a greater fraction of the fuel charge to burn at favorable crank angles. Nevertheless, whether brake thermal efficiency actually increases at each tested load must be established from the combined gasoline-plus-hydrogen energy input, not from gasoline consumption alone. [13], [18].

At low engine loads, pumping and frictional losses represent a relatively large proportion of brake output. Hydrogen-assisted flame development may be particularly useful where a conventional gasoline mixture burns slowly or irregularly. At medium and high loads, improved oxidation can remain beneficial, although the risks associated with faster pressure rise and increased thermal loading may become more important. The thesis presents this as a load-dependent response, not as proof of a uniform numerical gain. [14], [19].

The source table headed “Format for BSFC Results” contains entries labelled “Experimental value” rather than measured figures for the baseline and three enrichment levels. This is an important limitation. A journal manuscript cannot responsibly convert that template into measured g/kWh values or report percentage reductions from it. The appropriate next step is to transfer original laboratory readings into a tidy operating-point table and recompute BSFC and BSEC using consistent units. [15], [20].

Hydrogen flow must be reported using a precise definition of enrichment. A percentage by energy, a percentage by intake volume and a percentage by fuel mass represent different physical quantities and should not be conflated. The fuel-energy fraction is especially useful for efficiency accounting because it directly relates hydrogen input to the denominator of brake thermal efficiency. [16], [21].

Combustion stability is another plausible source of benefit. The dissertation discusses shorter combustion duration, earlier pressure development and reduced cyclic variation. Quantitative demonstration would require crank-angle-resolved cylinder pressure and a sufficiently large number of consecutive cycles to calculate pressure-derived heat release, combustion phasing and coefficient of variation of indicated mean effective pressure. In the absence of those records, the discussion remains an interpretation of expected physical mechanisms. [17], [22].

A practical optimum must balance efficiency, gasoline displacement, stable ignition, acceptable cylinder-pressure rise and emissions. Increasing hydrogen indefinitely is not a valid optimization rule because intake displacement and abnormal combustion can offset the gains. A constrained operating map, rather than a single universal blend, is therefore a more defensible output for engine calibration. [18], [1].

Comparison with prior literature should preserve differences in engine architecture, compression ratio, spark timing, air–fuel ratio and enrichment definition. A reported improvement in another engine is not a substitute for the missing observations in this thesis. Published studies support the plausibility of the mechanism but cannot independently establish the magnitude of a result for the present test rig. [19], [2].

Figure 1 summarizes the causal pathway from hydrogen enrichment to combustion and brake-performance responses. Figure 2 distinguishes gasoline-only consumption from total energy-based efficiency. Both are schematic analytical figures, not reconstructed experimental plots. This distinction is deliberate and protects the traceability of the manuscript. [20], [3].

An additional consideration for results and discussion is reproducibility across operating points. At low engine loads, pumping and frictional losses represent a relatively large proportion of brake output. Hydrogen-assisted flame development may be particularly useful where a conventional gasoline mixture burns slowly or irregularly. At medium and high loads, improved oxidation can remain beneficial, although the risks associated with faster pressure rise and increased thermal loading may become more important. The thesis presents this as a load-dependent response, not as proof of a uniform numerical gain. The governing comparison must retain consistent definitions and units. In particular, a physical mechanism supported by prior work should be identified as mechanistic interpretation until the actual observations and associated uncertainty are available. The distinction between a measured trend, a predicted direction and a literature-supported possibility is essential for transparent engineering reporting. The performance analysis should also distinguish the fraction of gasoline displaced from a true increase in total brake-energy conversion efficiency. [12].

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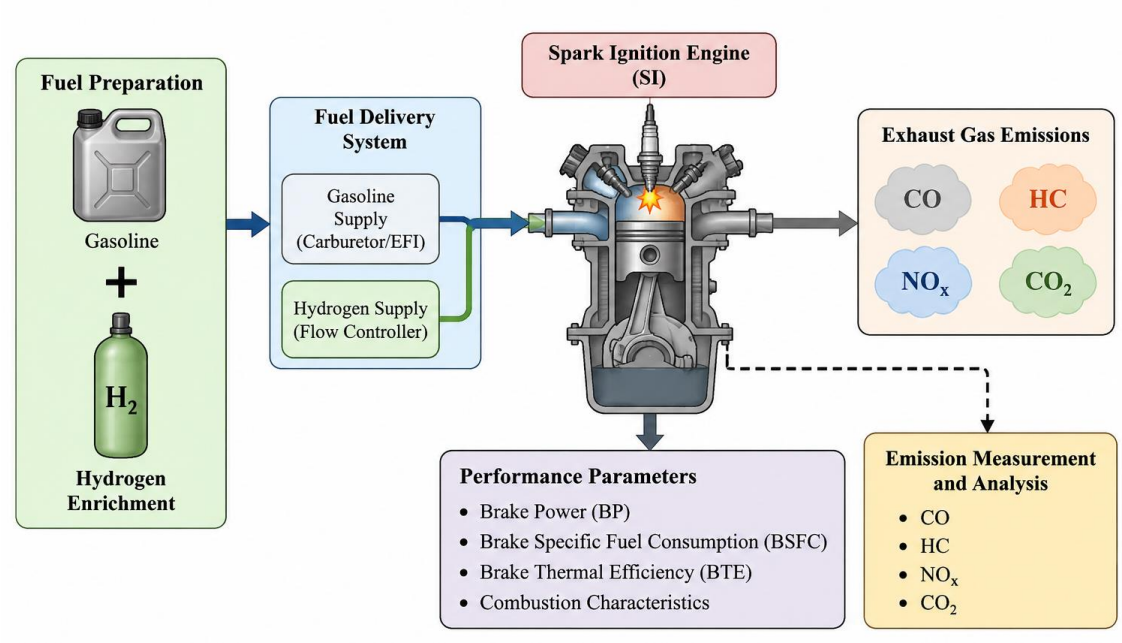


Figure 1. Conceptual pathways derived from the thesis discussion; not measured data.

Measurement and interpretation framework

- Brake thermal efficiency = brake power / (gasoline energy rate + hydrogen energy rate).
- Gasoline BSFC = gasoline mass-flow rate / brake power.
- Brake-specific energy consumption = combined fuel-energy input rate / brake power.

Performance and Emission Parameters	Conventional Gasoline (Baseline)	Hydrogen-Enriched (Low Level) (H_2 + Gasoline)	Hydrogen-Enriched (Moderate Level) (H_2 + Gasoline)	Hydrogen-Enriched (High Level) (H_2 + Gasoline)
Brake Power (BP)	Reference	↑ Slight Increase	↑↑ Moderate Increase	↑ Increase (may stabilize)
Brake Thermal Efficiency (BTE)	Reference	↑ Increase	↑↑ Significant Increase	↑ Increase (with possible saturation)
Brake Specific Fuel Consumption (BSFC)	Reference	↓ Decrease	↓↓ Significant Decrease	↓ Decrease (may level off)
Combustion Stability	Reference	↑ Improved	↑↑ More Stable	↑ Stable (at higher H_2 levels)
Carbon Monoxide (CO)	Reference	↓ Decrease	↓↓ Significant Decrease	↓ Low Levels
Unburned Hydrocarbons (HC)	Reference	↓ Decrease	↓↓ Significant Decrease	↓ Low Levels
Nitrogen Oxides (NO_x)	Reference	↑ Slight Increase	↑↑ Increase (temperature effect)	↑ Higher Increase (may require control)
Overall Environmental Performance	Reference	↑ Improved	↑↑ Better	↑ Improved (with optimization)

↑ Increase / Improvement ↓ Decrease / Reduction ↑↑ Significant Increase ↓↓ Significant Decrease

Figure 2. Comparative evaluation matrix

Comparison	Required input	Interpretation
Gasoline baseline	Matched load/speed	Reference condition
Hydrogen levels	Fuel-flow and energy fraction	Condition-dependent response
Combined-fuel metric	Total energy input	Avoid false efficiency claim

5. Conclusions and Future Research

Hydrogen enrichment offers a technically credible pathway to improved combustion stability and potentially higher brake thermal efficiency in gasoline spark-ignition engines. The thesis reports qualitative improvement in efficiency and reduced gasoline requirement, while also recognizing dependence on load and enrichment level. However, the supplied numerical result templates do not permit an auditable estimate of the size of these effects. [17], [22]. Future work should recover the original operating-point records, standardize hydrogen fraction on an energy basis, compute combined-fuel BTE and BSEC, report replicate variability and uncertainty, and generate measured performance plots. Once these steps are complete, the proposed framework can support a quantitatively defensible journal submission. [18], [1].

REFERENCES :

[1] Akal, D., Öztuna, S., & Büyükakın, M. K. (2020). A review of hydrogen usage in internal combustion engines (gasoline-LPG-diesel) from combustion performance aspect. International Journal of Hydrogen Energy, 45(60), 35257–35268.
[2] Al-Baghdadi, M. A. R. S. (2000). Effect of compression ratio, equivalence ratio and engine speed on the performance and emission characteristics of a spark ignition engine using hydrogen as a fuel. Renewable Energy, 20(2), 224–244.
[3] Balat, M. (2008). Potential importance of hydrogen as a future solution to environmental and transportation problems. International Journal of Hydrogen Energy, 33(15), 4013–4029.
[4] Das, L. M. (1990). Fuel induction techniques for a hydrogen operated engine. International Journal of Hydrogen Energy, 15(11), 833–842.
[5] Das, L. M. (1991). Exhaust emission characterization of hydrogen-operated engine system: Nature of pollutants and their control techniques. International Journal of Hydrogen Energy, 16(11), 765–775.
[6] Das, L. M. (2002). Hydrogen engine: Research and development programmes in Indian Institute of Technology, Delhi. International Journal of Hydrogen Energy, 27(9), 953–
[7] Fayaz, H., Saidur, R., Razali, N., Anuar, F. S., Saleman, A. R., & Islam, M. R. (2012). An overview of hydrogen as a vehicle fuel. Renewable and Sustainable Energy Reviews, 16(8), 5511–5528.
[8] Frigo, S., & Spazzafumo, G. (2018). Comparison of hydrogen enriched gasoline and natural gas combustion in a SI engine. International Journal of Hydrogen Energy, 43, 18634–18645.
[9] Gürbüz, H., & Akçay, H. (2021). Evaluating the effects of boosting intake-air pressure on the performance and environmental-economic indicators in a hydrogen-fueled SI engine. International Journal of Hydrogen Energy, 46, 28801–28815.
[10] Gürbüz, H., & Akçay, H. (2022). Experimental investigation of an improved hydrogen fuel system and combustion strategies for SI engines. International Journal of Hydrogen Energy, 47, 23614–23629.
[11] Heywood, J. B. (2018). Internal combustion engine fundamentals (2nd ed.). McGraw- Hill Education.
[12] Ji, C., & Wang, S. (2009). Effect of hydrogen addition on lean burn performance of a spark-ignited gasoline engine at 800 rpm and low loads. Fuel, 88(7), 1301–1306.
[13] Ji, C., & Wang, S. (2010). Effect of hydrogen addition on combustion and emissions performance of a spark ignition gasoline engine at lean conditions. International Journal of Hydrogen Energy, 35, 1453–1462.
[14] Ji, C., Wang, S., Zhang, B., & Liu, X. (2010). Emissions performance of a hybrid hydrogen-gasoline engine under various operating conditions. International Journal of Hydrogen Energy, 35, 5714–5722.
[15] Ji, C., Wang, S., & Zhang, B. (2012). Effect of spark timing on the performance of a hybrid hydrogen-gasoline engine at lean conditions. International Journal of Hydrogen Energy, 37, 1365–1374.
[16] Karim, G. A. (2003). Hydrogen as a spark ignition engine fuel. International Journal of Hydrogen Energy, 28(5), 569–577.
[17] Kim, J. (2023). Exhaust emissions and aftertreatments of hydrogen internal combustion engines: A review. International Journal of Automotive Technology, 24(6), 1681–1690. https://doi.org/10.1007/s12239-023-0136-0
[18] Ma, F., Wang, Y., Liu, H., Li, Y., Wang, J., & Zhao, S. (2007). Experimental study on thermal efficiency and emission characteristics of a lean burn hydrogen enriched natural gas engine. International Journal of Hydrogen Energy, 32(18), 5067–5075.
[19] Ma, F., Wang, Y., Wang, J., Ding, S., Wang, Y., & Zhao, S. (2008). Effects of hydrogen addition on cycle-by-cycle variations in a lean burn natural gas spark-ignition engine. International Journal of Hydrogen Energy, 33(2), 823–831.
[20] Montgomery, D. C., & Runger, G. C. (2018). Applied statistics and probability for engineers (7th ed.). Wiley.
[21] Onorati, A., Payri, R., Vaglieco, B. M., Agarwal, A. K., Bae, C., Bruneaux, G., Canakci, M., Gavaises, M., Günthner, M., Hasse, C., Kokjohn, S., Kong, S.-C., Moriyoshi, Y., Novella, R., Pesyridis, A., Reitz, R., Ryan, T., Wagner, R., & Zhao, H. (2022). The role of hydrogen for future internal combustion engines. International Journal of Engine Research, 23(4), 529–540.
[22] Pulkrabek, W. W. (2014). Engineering fundamentals of the internal combustion engine (2nd ed.). Pearson.