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(Research Article)

Simulation Study on the Effects of Hydrogen-Rich Gas Addition on the Performance and Emissions of Diesel Engines for Nearshore Fishing Vessels

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Abstract

This study investigates the influence of HHO gas enrichment on the combustion and emission characteristics of a diesel engine operating at 2200 rpm under various load conditions. Experimental measurements and AVL Boost simulations were conducted to evaluate the effects of hydrogen addition on in-cylinder pressure, air–fuel ratio, and key emission parameters. The results show that HHO, owing to its high flame speed, carbon-free composition, and additional oxygen content, significantly improves combustion quality and engine efficiency. Brake-specific fuel consumption decreased by 7–10% at medium loads, while CO and soot emissions were reduced by 20–35% and 30–40%, respectively, indicating more complete and cleaner combustion. However, NO_x emissions increased slightly by about 10–15% at higher loads due to elevated peak temperatures. The air–fuel equivalence ratio (λ) decreased with increasing HHO proportion but remained above 1.2, ensuring stable operation. Overall, HHO enrichment proves to be a feasible and effective approach to enhancing the thermal efficiency and environmental performance of diesel engines, particularly by reducing soot and CO emissions while maintaining stable combustion behavior.

Keywords: HHO; AVL Boost; Emission; Diesel engine

1. Introduction

Diesel engines emit particulate matter (PM), commonly known as soot, which poses serious health risks and contributes to air pollution and climate change. PM forms mainly due to heterogeneous air–fuel mixing and the slow flame speed inherent in diesel combustion. Structural modifications to mitigate this issue are often complex and costly, while particulate filters may clog during long-term operation, increasing backpressure and maintenance requirements. Therefore, improving combustion quality without major hardware changes is considered a more practical approach.

Hydrogen enrichment in diesel engines has been widely investigated because hydrogen features high flame velocity, wide flammability limits, and excellent diffusivity, leading to faster and more complete combustion. However, the large-scale use of pure hydrogen is limited by its storage, transportation, and production difficulties. A feasible alternative is on-board generation of hydrogen-rich gas through electrolysis.

The produced mixture, known as HHO or Brown's gas, contains roughly 60% H_2, 30% O_2, and small quantities of H_2O vapor and active radicals such as O and OH. With its low ignition energy and strong oxidation potential, HHO enhances C–H bond oxidation and supports cleaner combustion. It can be generated on demand and directly supplied to the intake manifold, avoiding the need for high-pressure tanks and making integration on vehicles or generators straightforward.

Experimental studies worldwide have confirmed that adding HHO improves engine efficiency and combustion characteristics. Most results indicate lower brake specific fuel consumption (BSFC) and higher brake thermal efficiency (BTE), owing to better mixture uniformity and higher energy density. Gad and Abdel Razek [1] reported BSFC reductions

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up to 3%, while Premkartikkumar et al. [5] observed BTE gains exceeding 10% at full load. HHO also enhances in-cylinder combustion by increasing peak pressure and heat release rate (HRR), which reflects faster flame propagation and more complete oxidation. Duarte-Forero et al. [10] found pressure rises of 3–12% depending on flow rate, while Gad and Abdel Razek [1] reported HRR improvements up to 6.5%. Although minor changes in ignition delay have been observed, overall combustion becomes more uniform and efficient.

Regarding emissions, HHO addition markedly decreases CO, HC, and smoke due to its carbon-free composition and the presence of active oxygen species that promote oxidation. CO reductions of 20–25% and smoke opacity decreases up to 35% have been documented [1, 7, 13]. However, several studies also noted increased NO_x emissions under high-load conditions because of higher peak temperatures, though this effect can be mitigated by exhaust gas recirculation or by operating under partial-load conditions where HHO's moisture content reduces flame temperature. In summary, HHO enrichment offers a promising route to enhance diesel engine efficiency and reduce major pollutants without extensive mechanical modification. Its on-demand generation capability and ease of integration make it a viable step toward cleaner and more sustainable diesel combustion.

Despite the promising outcomes reported in previous studies, the application of HHO technology to diesel engines still faces several challenges. The majority of published works have been conducted under limited operating conditions, often with small-scale test benches, without a comprehensive evaluation of the interactions between HHO flow rate, combustion behavior, and emission formation. Moreover, variations in electrolyzer design, gas composition, and intake integration methods can lead to inconsistent results, making it difficult to establish an optimal configuration for practical use. Therefore, this study aims to address these gaps by experimentally and numerically investigating the influence of HHO enrichment on the combustion and emission characteristics of a diesel engine. A detailed simulation model was developed in AVL Boost based on the structural parameters of the diesel engine to predict the combustion process and performance variations when hydrogen-rich gas is introduced into the intake manifold. The study aims to provide a deeper understanding of the thermodynamic behavior of HHO-assisted diesel combustion and to identify the most effective HHO substitution ratios that improve engine efficiency while reducing harmful emissions.

2. Material and methodology

2.1. Study procedure

To evaluate the effects of HHO enrichment on the power output and emissions of a diesel engine, a multi-step procedure (Figure 1) was conducted as follows:

- **Step 1:** Experimental tests were performed to establish the engine's full-load and speed characteristics at 2200 rpm, thereby determining the key experimental parameters.
- **Step 2:** A diesel engine model was developed based on the technical specifications provided by the manufacturer. The model's accuracy was validated by comparing selected simulation parameters with corresponding experimental data.
- **Step 3:** Once the model achieved acceptable accuracy, simulations were carried out at 2200 rpm, where diesel fuel was partially substituted by HHO at energy replacement ratios of 5%, 10%, 15%, and 20%, under four load conditions: 25%, 50%, 75%, and 100%.
- **Step 4:** For each load condition, the optimal HHO substitution ratio was determined based on the minimum brake-specific fuel consumption. This ratio was then considered the most appropriate condition for assessing emission performance.

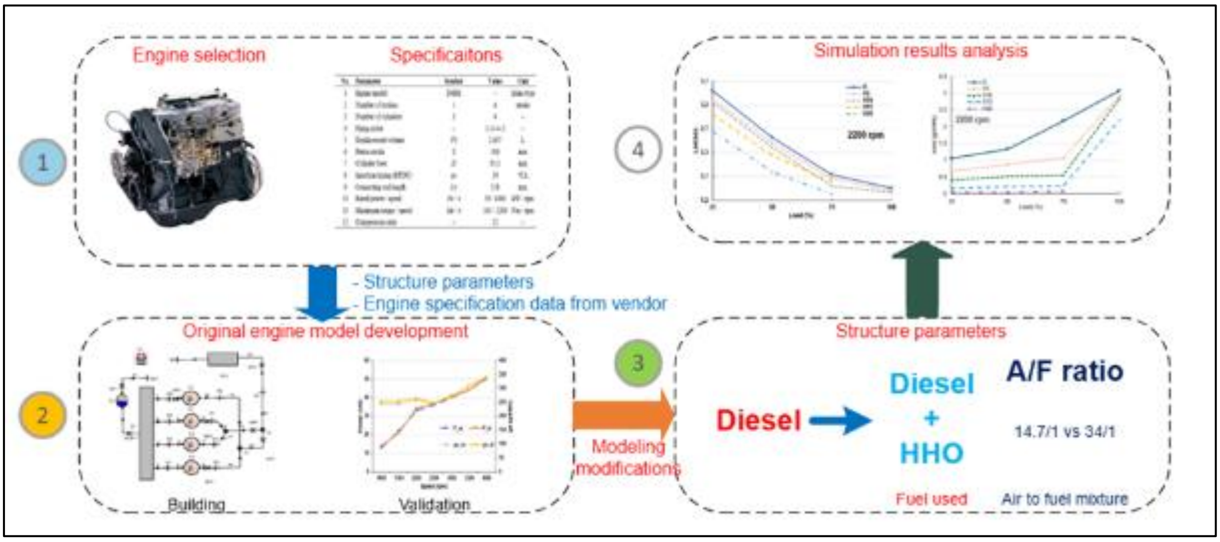

Figure 1 The study procedure flowchart

2.2. Simulation fuel

Table 1 presents a comparison of the fuel properties. The referenced characteristics are sourced from the literature [16], while the biogas composition data were derived from practical applications.

Table 1 Main characteristics of fuels [16]

No.	Property	Unit	Diesel	Hydrogen
1	Chemical formula	–	C_9–C_{25}	H_2
2	Density at 0 °C and 0.1 MPa	kg/m^3	≈ 850	≈ 0.09
3	Boiling point	°C	180–360	–253
4	Kinematic viscosity at 40 °C	mm^2/s	2–4.5	–
5	Relative density (air = 1)	–	≈ 0.654	≈ 0.0695
6	Self-ignition temperature	°C	200–300	560–585
7	Molecular weight	–	200–300	2
8	Main elemental composition	% by mass	84–87 C, 13–16 H	100 H
9	Heat of vaporization	kJ/kg	≈ 250	≈ 120
10	Freezing point	°C	–5 to –25	–260
11	Auto-ignition energy	mJ	–	0.017
12	Cetane number	–	≈ 53	5–10
13	Lower heating value (LHV)	MJ/kg	42.5	120
14	Laminar flame speed	m/s	≈ 0.4	≈ 2.7
15	Stoichiometric air requirement	kg air/kg fuel	≈ 14.6	34.5
16	Auto-ignition limits	–	0.82–12	0.14–9.85
17	Explosive limits in air	vol.%	0.6–7.5	4–77
18	Diffusion coefficient	cm^2/s	–	0.63

2.3. Simulation model development

The engine investigated in this study is the Hyundai D4BB diesel engine. The main technical specifications of the engine are presented in Table 2.

Table 2 The test engine specifications

No.	Parameter	Symbol	Value	Unit
1	Engine model	D4BB	–	Inline type
2	Number of strokes	i	4	stroke
3	Number of cylinders	I	4	–
4	Firing order	–	1–3–4–2	–
5	Displacement volume	V_h	2.607	L
6	Piston stroke	S	100	mm
7	Cylinder bore	D	91.1	mm
8	Injection timing (BTDC)	φ_s	20	°CA
9	Connecting rod length	L	158	mm
10	Rated power/speed	Ne / n	59 / 4000	kW / rpm
11	Maximum torque/speed	Me / n	165 / 2200	Nm/rpm
12	Compression ratio	–	22	–

When direct measurement instruments are unavailable or experimental setups become too complex for analyzing certain parameters, modeling serves as an effective alternative approach. In this study, the commercial software AVL Boost was employed to develop a simulation model aimed at predicting the effects of fuel type on combustion behavior, in-cylinder characteristics, and overall engine performance. The model, illustrated in Figure 2, was constructed based on the structural specifications of the engine. The simulation process applies the first law of thermodynamics to determine the in-cylinder pressure cycle. Furthermore, the Fractal combustion model, wall heat transfer analysis, and gas property variations as functions of pressure, temperature, and composition were incorporated into the developed model.

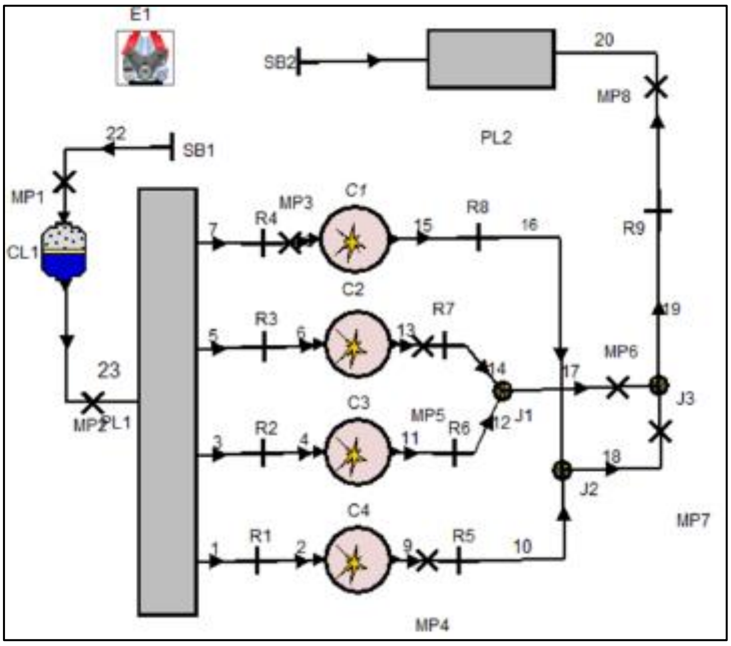

Figure 2 Developed model of the engine in AVL Boost

Where: CL1: Intake air filter; SB1: Inlet boundary condition element of the model; SB2: Outlet boundary condition element of the model; PL1-2: Plenum; MP1–MP8: Measuring elements; C1–C4: Engine cylinders; E1: Engine; R1–R9: Flow resistance elements; I1: HHO injection nozzle; J1–J3: Connection elements.

2.4. Simulation scenario

The simulation procedure was carried out through the following steps:

Step 1: The amount of diesel supplied per cycle at each load was determined experimentally. HHO substitution ratios of 5%, 10%, 15%, and 20% were applied to partially replace diesel fuel, with the substituted diesel calculated using Eq. (1).

Diesel substitution ratio by:

$$R = \frac{m_{Dreplace}}{m_{Doriginal}} \times 100\% \quad (1)$$

Equivalent H_2 quantity:

$$m_{H2} = m_{Dreplace} \times \frac{LHV_D}{LHV_H} \quad (2)$$

Step 2: The equivalent HHO quantity was computed based on energy equivalence between the replaced diesel and supplied HHO, as expressed in Eq. (2), where $m_{Dreplace}$ and $m_{Doriginal}$ are the substituted and initial diesel masses, and LHV_D and LHV_H are their respective lower heating values (MJ/kg).

Step 3: Engine simulations were performed at 25–100% load for HHO ratios H5–H20. Diesel and HHO mass inputs were defined per cycle after substitution, with boundary conditions including HHO injection pressure, combustion coefficient, and turbulence factor.

Step 4: Only cases with $\lambda > 1.2$ were analyzed to ensure complete combustion. Results were normalized by load to evaluate the influence of HHO enrichment on engine performance and emissions.

3. Results and discussion

3.1. Validation of the simulation model

The experimental measurements provided essential input parameters for the model as well as reference data for assessing its reliability. Model calibration was performed by comparing selected output parameters from the simulation with corresponding experimental results and iteratively adjusting the tuning parameters within the model until the deviation between simulation and experiment was reduced to less than 5%. At this point, the model was considered sufficiently accurate and reliable for further simulation analyses.

Figure 3 presents the comparison between the simulated and experimental results used to evaluate the model accuracy. The average deviation between simulation and experimental data in all comparison cases did not exceed 5%. Therefore, the engine model developed in AVL Boost can be considered sufficiently accurate to serve as a reference for subsequent simulation studies.

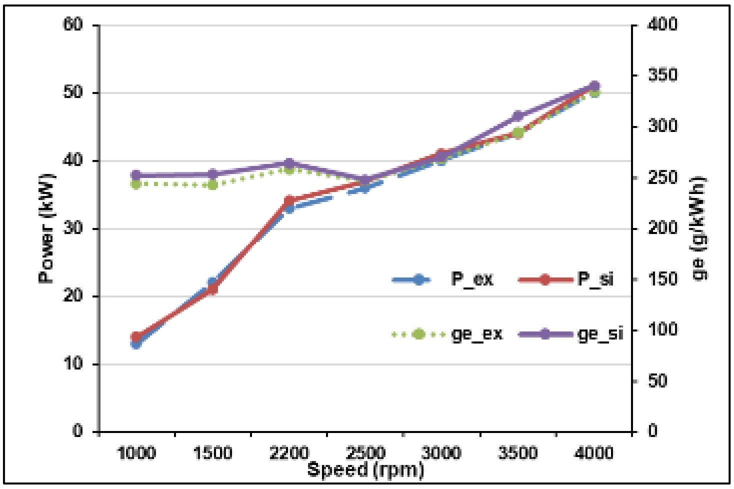

Figure 3 Comparison of brake power and torque at full load conditions

3.2. The effects of HHO on engine performance

Figure 4 illustrates the variation of the lambda coefficient when the engine operates at 2200 rpm. For the baseline diesel engine, as the load increases, the amount of injected fuel per cycle rises while the intake air remains nearly constant, resulting in a decrease in the lambda coefficient. When hydrogen is supplied at substitution ratios of 5%, 10%, 15%, and 20%, the lambda coefficient also decreases compared with the original diesel engine at the same load. The higher the hydrogen fraction, the lower the lambda value, because part of the intake air is displaced by hydrogen in the combustion chamber. Moreover, the theoretical air–fuel ratio (A/F) of diesel is approximately 14.8:1, whereas that of hydrogen is around 34:1, indicating that a greater amount of air is theoretically required for the complete combustion of both fuels.

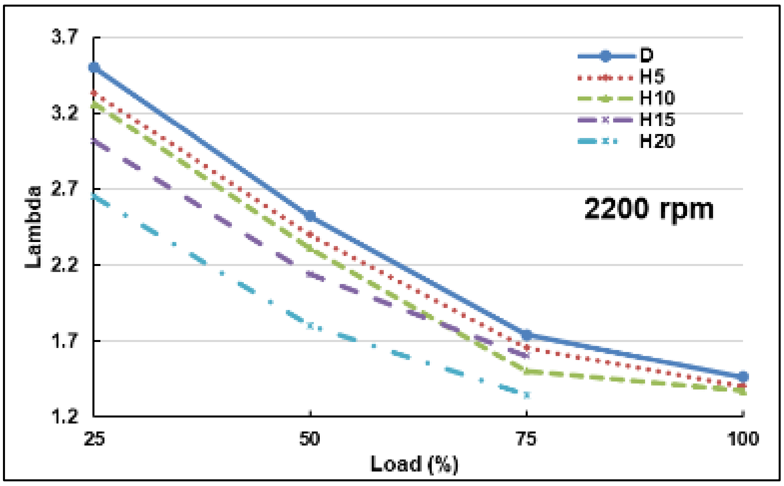

Figure 4 The variation of the lambda coefficient with different fuel cases

In most diesel engines equipped with a mechanical injection pump, black smoke typically begins to appear when the lambda coefficient drops to about 1.2. Therefore, in this simulation study, the minimum lambda value was set at 1.2 for the diesel engine. At each load condition, the hydrogen substitution ratio was increased only until the lambda reached 1.2. Consequently, the analysis of hydrogen enrichment effects on the performance and emissions of the engine was conducted only for cases where the lambda coefficient was equal to or greater than 1.2.

When comparing fuel economy performance, since biogas has a significantly lower calorific value than diesel, the comparison should be based on the brake specific energy consumption (BSEC), which is determined using the following Eq. (3):

$$BSEC = \frac{m_D \times LHV_D + m_H \times LHV_H}{Ne} \quad (3)$$

Where: m_D and m_H are the mass of fuel diesel and hydrogen (kg), LHV_D and LHV_H are the lower heating value of fuel diesel and hydrogen (kJ/kg), and Ne is brake power (kW).

Figure 5 shows the variation of BSEC at 2200 rpm under different load conditions. Hydrogen enrichment was found to reduce BSEC in the operating regions where the lambda coefficient exceeded 1.2. This reduction occurs because the addition of hydrogen enhances the combustion process, allowing more complete burning of diesel fuel and thereby increasing engine power output. As the hydrogen substitution ratio increases, BSFC continues to decrease, with the most pronounced improvement observed at 50%, 75%, and 100% load conditions.

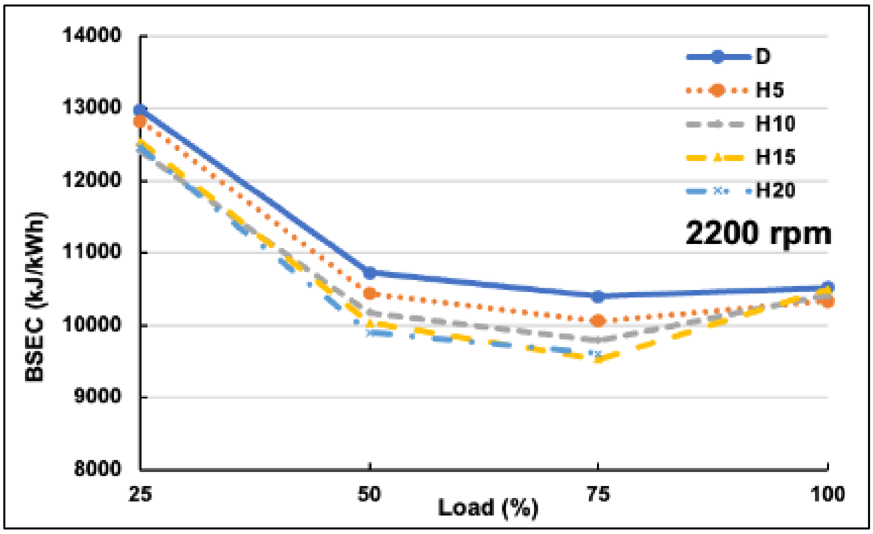

Figure 5 The variation of BSEC with different fuel cases

3.3. The effects of HHO on engine pollutants comparison

Figures 6 to 8 illustrate the harmful pollutants of soot, CO, and NO_x from the engine operating under different load conditions at an engine speed of 2200 rpm, using diesel and HHO as additives.

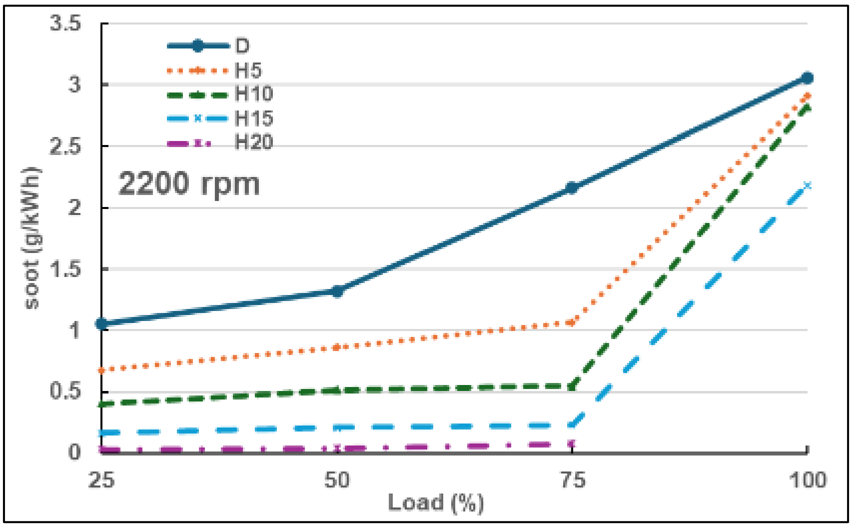

Figure 6 The variation of soot with different fuel cases

Figure 6 illustrates the variation of soot emissions when the engine is supplied with HHO gas under different load conditions. As the engine load increases, soot emissions rise because the amount of injected diesel per cycle increases. However, the addition of HHO gas tends to reduce soot formation, and this reduction becomes more significant as the HHO substitution ratio increases. The decrease in soot emissions is mainly attributed to the lower diesel share in the combustion process and the enhanced oxidation promoted by the hydrogen and oxygen components of HHO, which improve combustion completeness. The most noticeable soot reduction was observed at medium and high loads, particularly at 50% and 75% load conditions.

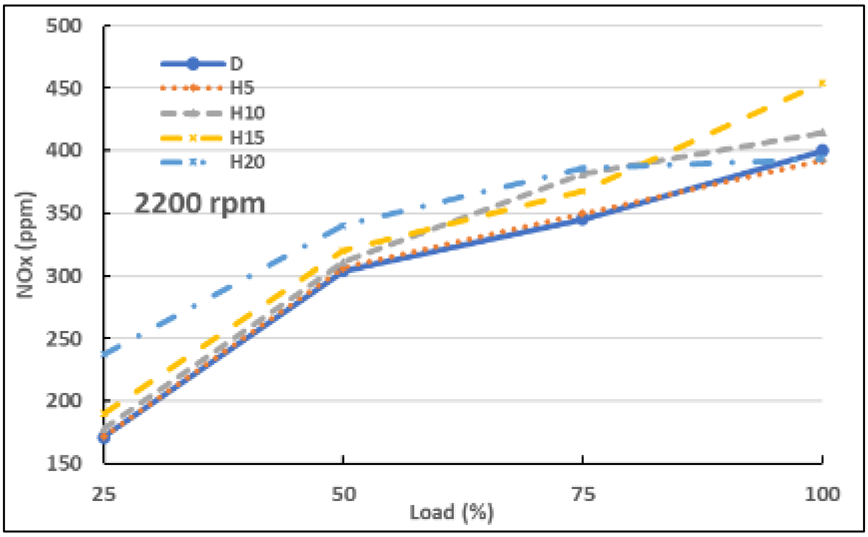

Figure 7 The variation of NO_x with different fuel cases

Figure 7 presents the variation of NO_x emissions when the engine is enriched with HHO gas under different load conditions. As engine load increases, NO_x emissions tend to rise because the higher amount of injected fuel per cycle leads to increased in-cylinder temperatures, thereby promoting thermal NOx formation. Moreover, the introduction of HHO gas further elevates NO_x emissions, with higher substitution ratios resulting in greater increases. This phenomenon can be explained by the improved mixture homogeneity, higher heating value, and faster flame propagation associated with HHO addition, all of which contribute to higher combustion temperatures and consequently greater NO_x generation.

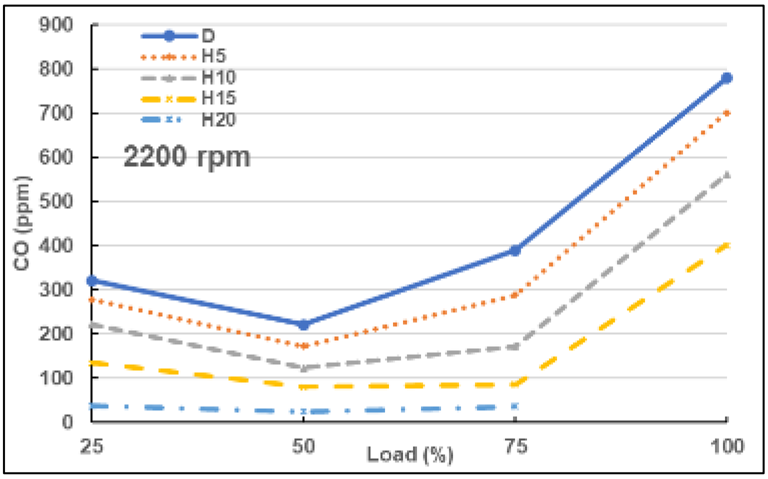

Figure 8 The variation of CO with different fuel cases

Figure 8 illustrates the variation of CO emissions when the engine is supplied with HHO gas under different load conditions. CO emissions at 25% load were higher than those at 50% load, while at full load (100%) the CO concentration increased by approximately 2.1 times compared with the 25% load condition. This occurs because, at low load, the exhaust gas temperature is relatively low, resulting in limited oxidation of CO, whereas at high load, oxygen deficiency during combustion leads to a sharp rise in CO emissions. The addition of hydrogen through HHO enrichment tends to reduce CO emissions, and the higher the proportion of hydrogen substitution, the greater the reduction, owing to the enhanced oxidation and more complete combustion promoted by HHO.

The simulation results revealed the trends in engine performance and emission parameters depending on the load and hydrogen substitution ratio, as described above, and these can be explained as follows. In a diesel engine, increasing load is achieved by supplying a greater amount of fuel per cycle, while the intake air quantity remains nearly constant. When HHO is introduced into the intake manifold, a portion of the intake air is displaced by the HHO mixture, effectively reducing the total air charge. Consequently, as load increases, the air–fuel equivalence ratio (lambda) decreases, and with HHO enrichment, lambda drops even further. However, in this study, both the engine load and HHO substitution ratio were increased only up to the point where lambda remained above 1.2, ensuring sufficient oxygen availability for complete combustion. At each load condition, the influence of HHO enrichment on the engine's performance and emission characteristics varies depending on the extent of hydrogen addition.

When the engine operates under low-load conditions, the amount of injected diesel fuel per cycle is small, while the intake air volume remains relatively high, resulting in a low in-cylinder combustion temperature. Consequently, NOx emissions remain low, and soot formation follows the same trend, since soot production depends on the carbon concentration in the air–fuel mixture and the local gas temperature within the cylinder [1,13]. At low load, the exhaust gas temperature is also low, leading to poor CO oxidation and thus higher CO emissions compared with medium-load operation [7].

Under such conditions, partial replacement of diesel fuel with HHO does not markedly improve combustion or emission characteristics because only a small amount of HHO actually participates in the combustion process. The HHO–air mixture at low load is too lean to support stable flame propagation, as the injected diesel occupies only a small portion of the combustion chamber. Therefore, only the region where diesel and HHO overlap contributes to combustion, while the remaining HHO–air mixture is too lean and quickly quenched. This observation is consistent with the findings of Elgarhi [6] and Bhave et al. [7], who reported that HHO enrichment has negligible benefits at low load. Hence, a high HHO substitution ratio is not recommended under low-load conditions.

At medium-load operation, the total fuel quantity and heat release increase significantly, resulting in higher in-cylinder temperatures and consequently greater NO_x emissions [4,13]. The elevated temperature also enhances CO oxidation, causing a slight reduction in CO concentration as load increases [7,10]. In this range, HHO utilization becomes more effective, since a larger fraction of the supplied HHO participates in combustion. Increasing the HHO substitution ratio further raises the flame temperature, leading to higher NO_x emissions, as also observed by Rahman and Aziz [4] and Rimkus et al. [13]. However, the improved air–fuel homogeneity and faster flame speed of HHO promote more complete combustion, reducing both CO and HC emissions [1,5,7]. In addition, the lower carbon content of the overall mixture and the high-temperature conditions favor soot oxidation into CO and CO_2, thereby reducing soot emissions — a trend also reported by Gad and Abdel Razek [1].

At full load, the injected fuel per cycle is large, causing a substantial decrease in the lambda coefficient (averaging about 1.26). The limited oxygen availability leads to incomplete combustion, resulting in increased soot and CO emissions. Since the theoretical air requirement for complete combustion of 1 kg of HHO (approximately 34 kg of air) is much higher than that for diesel (about 14.8 kg of air), further increasing the HHO substitution ratio under full-load conditions significantly decreases lambda and aggravates oxygen deficiency. This causes incomplete combustion, reduced power output, and higher fuel consumption. These findings are consistent with the results of Duarte-Forero et al. [10] and Subramanian & Thangavel [11], who observed performance deterioration at high hydrogen ratios due to insufficient air supply. Therefore, under full-load operation, HHO should be introduced only at low substitution ratios to avoid excessive air–fuel imbalance and combustion inefficiency.

4. Conclusion

This study examined the effects of HHO gas enrichment on the combustion and emission characteristics of a diesel engine operating at 2200 rpm under various load conditions. The results demonstrated that HHO, with its high flame speed, carbon-free composition, and additional oxygen content, significantly improved the combustion quality and overall efficiency of the diesel engine.

A clear reduction in brake-specific fuel consumption was observed across most load conditions, especially at medium loads (50–75%), where the average decrease ranged from 7% to 10%, indicating improved thermal efficiency. CO emissions decreased considerably by about 20–35%, particularly at low loads, confirming a more complete oxidation process. Soot emissions were also reduced by 30–40% due to the oxygen-rich environment and enhanced flame propagation, which promote soot oxidation and suppress its formation. In contrast, NO_x emissions exhibited a slight increase of approximately 10–15% at higher loads, primarily due to the rise in peak combustion temperature caused by hydrogen enrichment. The air–fuel equivalence ratio gradually decreased with increasing HHO proportion, reflecting the combined effect of air displacement and more complete combustion, but remained above 1.2 in all cases, ensuring stable and efficient operation.

The analysis also showed that HHO has minimal influence at low load due to limited participation in the combustion process, whereas at medium load, the benefits are most pronounced. At full load, excessive HHO substitution reduces λ excessively and may cause incomplete combustion, suggesting that only moderate HHO addition is advisable under such conditions.

Overall, supplementing HHO gas into the intake system is a feasible and effective method to enhance diesel engine performance and reduce harmful emissions, particularly soot and CO. To minimize the moderate increase in NO_x emissions, further studies should focus on optimizing the HHO substitution ratio and combining it with combustion-temperature control strategies such as exhaust gas recirculation (EGR) or injection timing adjustment. These measures can help achieve cleaner, more efficient, and stable operation of HHO-assisted diesel engines under practical working conditions.

Nomenclature

Symbol	**Description**	**Unit**
ε	Compression ratio	–
S	Piston stroke	mm
D	Cylinder bore	mm
V_h	Displacement volume	L
N_e	Brake power	kW
M_e	Brake torque	Nm
m	Fuel mass	kg
λ	Air–fuel equivalence ratio (excess air ratio)	–
A/F	Stoichiometric air–fuel ratio	kg air/kg fuel
n	Engine speed	rpm
g_e	Brake specific fuel consumption	g/kWh
HRR	Heat release rate	J/°CA
T	Temperature	°C
P	Pressure	bar
ρ	Density	kg/m^3

Abbreviation	**Definition**
AVL	AVL Boost simulation software
HHO	Hydrogen-rich gas
PM	Particulate matter
NOx	Nitrogen oxides
CO	Carbon monoxide
CO_2	Carbon dioxide
HC	Hydrocarbons
BTE	Brake thermal efficiency
BSFC	Brake specific fuel consumption
BSEC	Brake specific energy consumption
LHV	Lower heating value

TDC	Top dead center
EGR	Exhaust gas recirculation

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Gad, M. S. and Abdel Razek, S. M. (2021), "Impact of HHO produced from dry and wet cell electrolyzers on diesel engine performance, emissions and combustion characteristics", International Journal of Hydrogen Energy. 46(43), pp. 22277-22291.

[2] Rodríguez Matienzo, Jorge M. (2018), "Influence of addition of Hydrogen produced on board in the performance of a stationary diesel engine", International Journal of Hydrogen Energy. 43(37), pp. 17889-17897.

[3] Ozcanli, Mustafa, Akar, Mustafa Atakan, Calik, Ahmet, and Serin, Hasan (2017), "Using HHO (Hydroxy) and Hydrogen enriched castor oil biodiesel in compression ignition engine", International Journal of Hydrogen Energy. 42(36), pp. 23366-23372.

[4] Rahman, Md Atiqur (2019), "Effect of induction Hydroxy and Hydrogen along with algal biodiesel blend in a CI engine: a comparison of performance and emission characteristics", Environmental Science and Pollution Research. 26(10), pp. 9552-9560.

[5] Premkartikkumar, SR, Annamalai, K, and Pradeepkumar, AR (2014), "Effectiveness of oxygen enriched Hydrogen-HHO gas addition on DI diesel engine performance, emission and combustion characteristics", Thermal Science. 18(1), pp. 259-268.

[6] Elgarhi, Ibrahim, El-Kassaby, Mohamed M., and Eldrainy, Yehia A. (2020), "Enhancing compression ignition engine performance using biodiesel/diesel blends and HHO gas", International Journal of Hydrogen Energy. 45(46), pp. 25409-25425.

[7] Bhave, Nikhil Aniruddha, Gupta, Mahendra M., and Joshi, Sandeep S. (2022), "Effect of oxy Hydrogen gas addition on combustion, performance, and emissions of premixed charge compression ignition engine", Fuel Processing Technology. 227, p. 107098.

[8] Baltacioglu, Mustafa Kaan, Kenanoglu, Raif, and Aydın, Kadir (2019), "HHO enrichment of bio-diesohol fuel blends in a single cylinder diesel engine", International Journal of Hydrogen Energy. 44(34), pp. 18993-19004.

[9] Yilmaz, Ali Can, Uludamar, Erinç, and Aydin, Kadir (2010), "Effect of Hydroxy (HHO) gas addition on performance and exhaust emissions in compression ignition engines", International Journal of Hydrogen Energy. 35(20), pp. 11366-11372.

[10] Duarte-Forero, Jorge, Mendoza-Casseres, Daniel, and Valencia-Ochoa, Guillermo (2021), "Energy, Exergy, and emissions (3E) assessment of a low-displacement engine powered by biodiesel blends of palm oil mill effluent (POME) and Hydroxy gas", Thermal Science and Engineering Progress. 26, p. 101126.

[11] Subramanian, Balaji and Thangavel, Venugopal (2020), "Experimental investigations on performance, emission and combustion characteristics of Diesel-Hydrogen and Diesel-HHO gas in a Dual fuel CI engine", International Journal of Hydrogen Energy. 45(46), pp. 25479-25492.

[12] Mendoza-Casseres, Daniel, Valencia-Ochoa, Guillermo, and Duarte-Forero, Jorge (2021), "Experimental assessment of combustion performance in low-displacement stationary engines operating with biodiesel blends and Hydroxy", Thermal Science and Engineering Progress. 23, p. 100883.

[13] Rimkus, Alfredas, et al. (2018), "An investigation of the efficiency of using O2 and H2 (Hydrooxile gas -HHO) gas additives in a ci engine operating on diesel fuel and biodiesel", Energy. 152, pp. 640-651.

[14] Liu, S, et al. (2016), "Effects on emissions of a diesel engine with premixed HHO", RSC advances. 6(28), pp. 23383-23389.

[15] Tüccar, Gökhan and Uludamar, Erinç (2018), "Emission and engine performance analysis of a diesel engine using Hydrogen enriched pomegranate seed oil biodiesel", International Journal of Hydrogen Energy. 43(38), pp. 18014-18019.

[16] Akhtar, Muhammad Usman Saeed, et al. (2025), "Performance and emissions characteristics of Hydrogen-diesel dual-fuel combustion for heavy-duty engines", International Journal of Hydrogen Energy.