

Performance Simulation and Optimization of Hydrogen-Diesel Dual Fueled Engine for Genset Application

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Abstract— The transport and power generation industries are coming under more pressure to lower carbon emissions and fossil fuel dependency. Hydrogen, as a clean alternative fuel, offers near-zero carbon emissions and high combustion efficiency. This study investigates hydrogen's application as a supplementary fuel in a 4-cylinder, 3.3 L turbocharged intercooled diesel genset engine operating at 1500 RPM. Simulations were performed using GT-SUITE under diesel-only and hydrogen-diesel dual-fuel modes. Two hydrogen supply strategies - Port Fuel Injection (PFI) and Direct Injection (DI) - were employed, with hydrogen substitution ranging from 10% to 50%. The simulations assessed thermal efficiency, fuel consumption, and emissions (NO_x, CO, CO₂, HC), maintaining constant power output. Results indicate notable improvements in thermal efficiency with dual-fueling. At 50% substitution and at 100% power, thermal efficiency increased from 41.79% to 41.84% in PFI mode, and 41.79% to 43.5% in DI mode. NO_x emissions remained nearly constant through optimized injection timing and air-fuel ratio. The study concludes that hydrogen-diesel dual-fuel operation, particularly with direct injection, significantly enhances efficiency without increasing NO_x emissions, offering a promising solution for cleaner and more efficient power generation.

Index Terms— Brake Specific Fuel Consumption (BSFC), Brake Specific Energy Consumption (BSEC), Diesel, Dual-Fuel, Genset Engine, Hydrogen, Hydrogen substitution ratio NO_x Emissions, Thermal Efficiency

I. INTRODUCTION

The demand for cleaner, more sustainable energy solutions has become a global priority due to growing environmental concerns, depleting fossil fuel reserves, and increasingly stringent emissions regulations. Among the many energy-consuming sectors, power generation is one of the most critical application especially in regions that rely on diesel generator sets (gensets) for backup and off-grid power. While diesel engines have long been valued for their efficiency, durability and reliability, they are also known to be major contributors to greenhouse gas emissions, particulate matter, and other harmful pollutants. On meeting the demands, there is rapid depletion of fossil fuels and thus demanding a shift towards alternative energy sources.

Thus, the alternative fuels such as biofuels, hydrogen, fuel cell, etc. are the most promising solutions to the problem of transportation and as well as for the power generation sources in the future. In case of diesel engines or genset engines, the emission norms are becoming stringent more and more because they produce higher NO_x and smoke emissions. Among these alternative fuels, hydrogen has emerged as a viable alternative fuel to diesel in internal combustion engines (ICEs). The appeal of hydrogen lies in its zero-carbon emission profile, abundant availability, and high specific energy content. When combusted, hydrogen produces only water vapor, making it a clean energy system.

Moreover, the ability to generate hydrogen through

renewable sources (e.g., solar or wind electrolysis) positions it as a long-term, environment friendly solution. However, the direct use of hydrogen in diesel engines introduces a number of challenges. Due to its low ignition energy, high flame speed, and wide flammability range, hydrogen can lead to uncontrolled combustion phenomena such as knocking, pre-ignition, and backfiring, especially at higher substitution ratios.

Furthermore, while hydrogen does not produce carbon-based emissions, it can contribute to elevated nitrogen oxides (NO_x) emissions due to higher in-cylinder temperatures. To mitigate these issues dual-fuel combustion has gained attention. In a hydrogen-diesel dual-fuel system, hydrogen is used as the primary energy source, while diesel serves as the pilot ignition fuel. This strategy enables significant diesel replacement, reduced CO₂ emissions, and improved thermal efficiency all while retaining the combustion stability and reliability of diesel ignition.

II. METHODS OF SIMULATION

The simulation work in this project was performed using GT- SUITE 1-D simulation tool. The approach of this study focuses on the performance simulation and optimization of a four-cylinder, turbocharged-intercooled diesel genset engine operating at 1500 RPM. For this simulation three fueling strategies were selected and the results were compared.

- The diesel only fueling

- The hydrogen-diesel dual-fuel hydrogen port fuel injection (PFI)
- The hydrogen-diesel dual-fuel hydrogen direct injection (DI)

The simulation evaluates three engine loads (10%, 50%, 100%) and three hydrogen substitution ratios (10%, 30%, 50%) for each load. For each hydrogen substitution ratio, quantity of hydrogen fuel is calculated based on Lower Heating Values (LHV) of diesel and hydrogen fuels such that total energy input from diesel and hydrogen fuels remains same as that of diesel fuel only.

III. SIMULATION SETUP

The diesel genset engine is selected for this project and the selected engine specifications are given in Table 1.

Table 1. Engine Specifications

Sl No	Specification	Value
1	Engine Type	Four-stroke, Four- cylinder CI Engine
2	Power	75 KW
3	Engine Speed	1500 rpm
4	Bore	95 mm
5	Stroke Length	117.5 mm
6	Connecting Rod Length	234.00 mm
7	Compression Ratio	16.1:1
8	Total Swept Volume	3.331 liters
9	Volume per Cylinder	0.8325 liters
10	Number of Valves	One intake and one exhaust valve per cylinder
11	Aspiration	Turbocharged-Intercooled
12	Brake Mean Effective Pressure (BMEP)	18 bar

The intake air composition was also considered, with the simulation assuming a standard atmospheric mix of nitrogen (79%) and oxygen (21%). The combustion process is simulated using the DI Wiebe model, which represents the rate of fuel burn as a function of crank angle, essential for accurately modelling hydrogen and diesel fuel mixtures. The GT-SUITE model of 'diesel only engine' is shown in Fig 1.

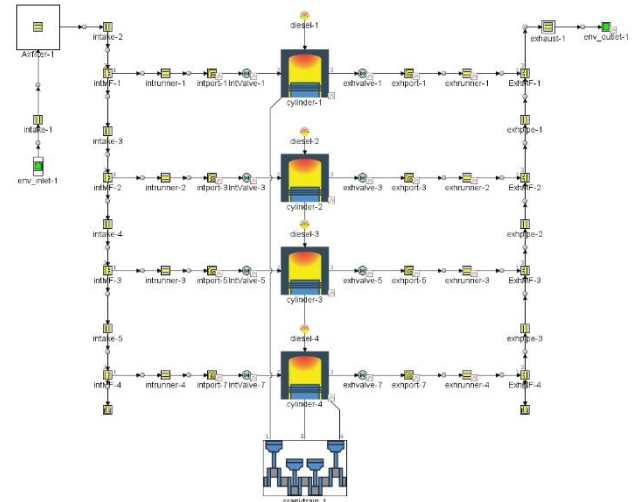


Fig 1. Simulation model of diesel only engine

The Hydrogen-Diesel Dual-Fuel Hydrogen Port Fuel Injection (PFI):

In Port Fuel Injection (PFI) mode, hydrogen is introduced into the intake port upstream of the intake valve, allowing it to mix with the incoming air charge before entering the combustion chamber. This approach results in a premixed and homogeneous charge, which generally promotes smoother and more stable combustion. The model of PFI mode is shown in Fig. 2 and parameters are given in Table 2.

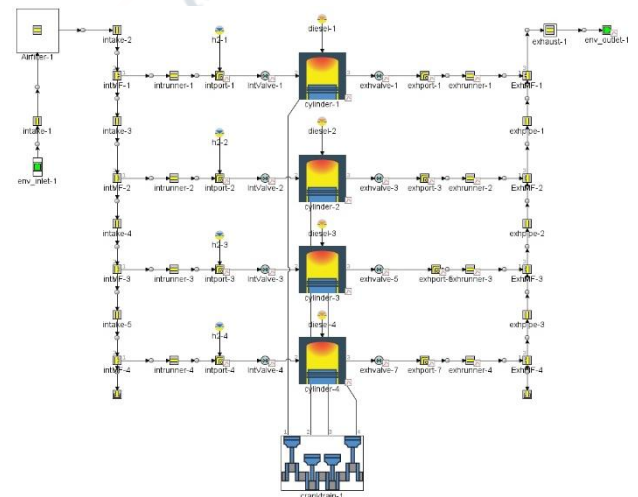


Fig 2. Simulation model of PFI mode

Table 2. PFI Parameters for hydrogen fuel injection

PFI Parameters	
Diesel Start of Injection (SOI)	8° CA BTDC
Hydrogen Start Injection Timing (SOI)	10° CA ATDC
Hydrogen Pulse Width	160° CA duration
Hydrogen Fuel Temperature	303 K
Diesel Injection Temperature	330 K

The Hydrogen-Diesel Dual-Fuel Hydrogen Direct Injection (DI):

In Direct Injection (DI) mode, hydrogen is injected directly into the combustion chamber near end of compression stroke, rather than into the intake port. This strategy enables more precise control over injection timing, stratification, and combustion phasing, making it suitable for higher hydrogen substitution ratios and improved efficiency at different engine loads. The model DI mode is shown in Fig.3. and the parameters are given in Table 3.

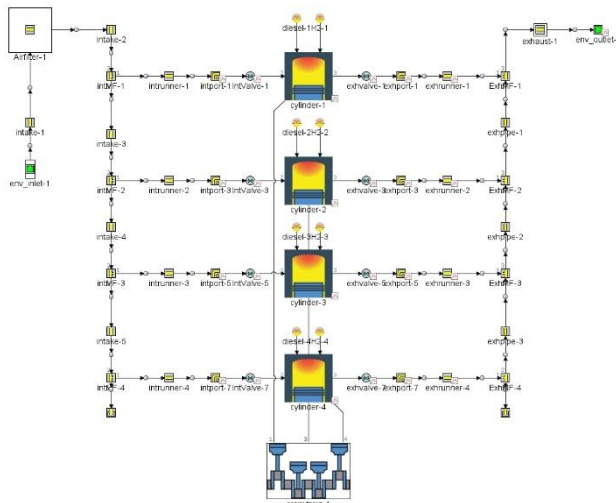


Fig 3. Simulation model of DI mode

Table 3. DI Parameters for hydrogen fuel injection

DI Parameters	
Diesel Start of Injection (SOI)	8° CA BTDC
Hydrogen Start Injection Timing (SOI)	25° CA BTDC
Hydrogen Fluid Temperature	303 K

Operating Conditions and Boundary Inputs:

Three load cases were simulated representing 100%, 50%, and 10% engine load conditions. Turbocharged-intercooled intake pressure and temperature values were provided as boundary inputs as mentioned in Table 4.

Table 4. Turbocharged-intercooled intake pressure and temperature values

Load (%)	Intake Pressure (bar abs)	Intake Temperature (°C)
100	2.5	60
50	1.8	40
10	1.35	32

Valve timing configuration for the engine is mentioned in Table 5 and these timings influence air-fuel mixing, volumetric efficiency, and combustion characteristics under both DI and PFI conditions.

Table 5. Valve Timing Configuration

Valve	Function	Angle [deg]
Intake Valve	IVO	13° BTDC
	IVC	16° ABDC
Exhaust Valve	EVO	12° BBDC
	EVC	18° ATDC

The simulation results for the diesel-only mode, the hydrogen-diesel dual-fuel modes using Port Fuel Injection (PFI) and Direct Injection (DI) strategies were analyzed. Performance parameters such as Brake Power, Brake Thermal Efficiency (BTE), Brake Specific Energy Consumption (BSEC) Brake Power (BP), NOx emissions, pressure and temperature were evaluated at three engine loads (100%, 50% and 10%) and three hydrogen substitution ratios (10%, 30% and 50%).

Brake Thermal Efficiency (BTE):

The brake thermal efficiencies of diesel only, hydrogen diesel dual fuel PFI mode and DI mode at varying engine loads are shown in Fig 4, Fig 5, Fig 6 and Table 6.

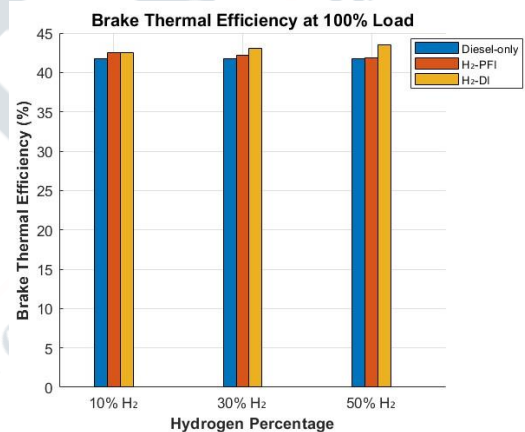


Fig 4. Comparison of BTE for Diesel-only, Hydrogen PFI, and Hydrogen DI modes at 100% Load

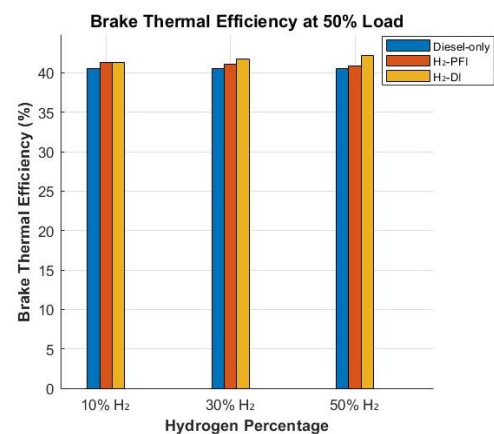


Fig 5. Comparison of BTE for Diesel-only, Hydrogen PFI, and Hydrogen DI modes at 50% Load

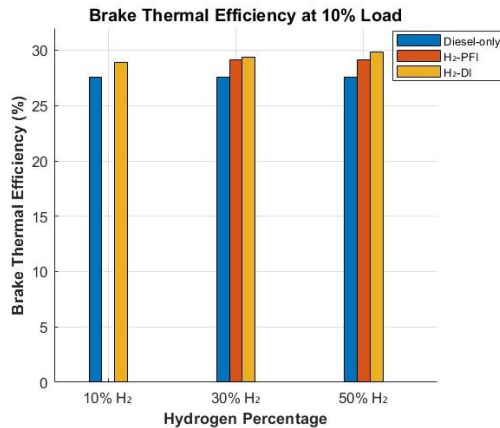


Fig 6. Comparison of BTE for Diesel-only, Hydrogen PFI, and Hydrogen DI modes at 10% Load

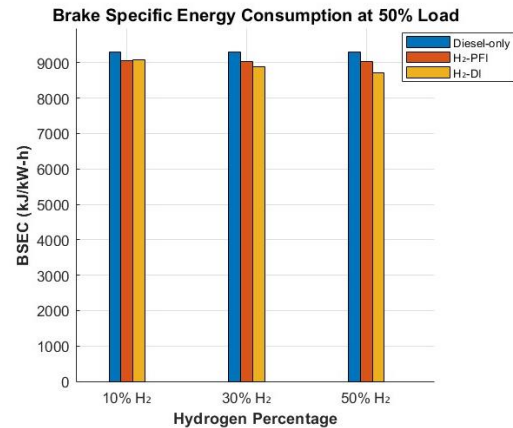


Fig 8. Comparison of BSEC for Diesel-only, Hydrogen PFI, and Hydrogen DI modes at 50% Load

Table 6. Comparison of BTE for Diesel-only, Hydrogen PFI and Hydrogen DI modes

Brake Thermal Efficiency (BTE) [%]							
Type	Diesel-only	H2-PFI			H2-DI		
Cases	100%	10% H2	30% H2	50% H2	10% H2	30% H2	50% H2
100% Load	41.8	42.49	42.18	41.85	42.53	43.04	43.5
50% Load	40.55	41.36	41.12	40.86	41.34	41.8	42.22
10% Load	27.58	---	29.17	29.11	28.89	29.4	29.87

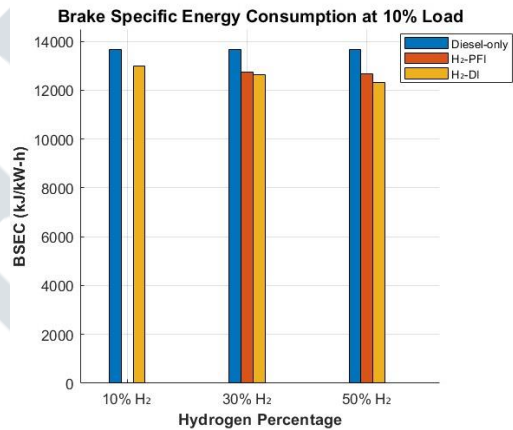


Fig 9. Comparison of BSEC for Diesel-only, Hydrogen PFI, and Hydrogen DI modes at 10% Load

Brake Specific Energy Consumption (BSEC):

The BSEC indicates the amount of energy input required for unit work done. The BSEC values for diesel-only, hydrogen– diesel dual fuel using Port Fuel Injection (PFI) and Direct Injection (DI) strategies across three engine load levels are shown in Fig 7, Fig 8, Fig 9 and Table 7.

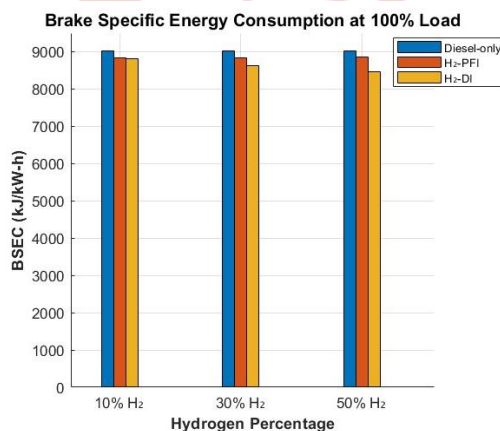


Fig 7. Comparison of BSEC for Diesel-only, Hydrogen PFI, and Hydrogen DI modes at 100% Load

Table 7. Comparison of BSEC for Diesel-only, Hydrogen PFI and Hydrogen DI modes

Brake Specific Energy Consumption (BSEC) [kJ/kW-h]							
Type	Diesel-only	H2-PFI			H2-DI		
Cases	100%	10% H2	30% H2	50% H2	10% H2	30% H2	50% H2
100% Load	9013	8826	8825	8862	8817	8634	8465
50% Load	9290	9067	9043	9043	9072	8890	8723
10% Load	13662	---	12739	12655	12979	12639	12327

From the simulation results, a decrease in BSEC with increased hydrogen substitution is observed for both PFI and DI strategies across all engine loads.

Brake Power (BP):

The brake power shows a slight improvement with increasing hydrogen percentage. This is due to the faster combustion characteristics of hydrogen, leading to a quicker pressure rise. The DI mode tends to show slightly better

power output than PFI due to more controlled combustion and improved mixing at lower loads shown in Fig 10, Fig 11, Fig 12 and Table 8.

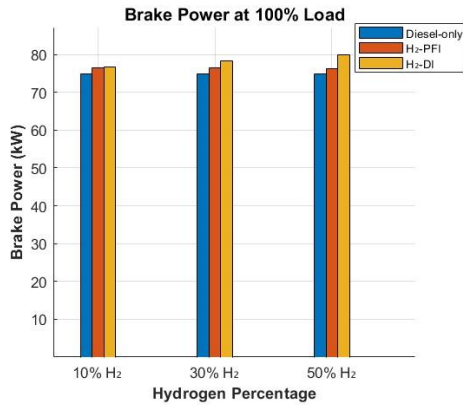


Fig 10. Comparison of BP for Diesel-only, Hydrogen PFI, and Hydrogen DI modes at 100% Load

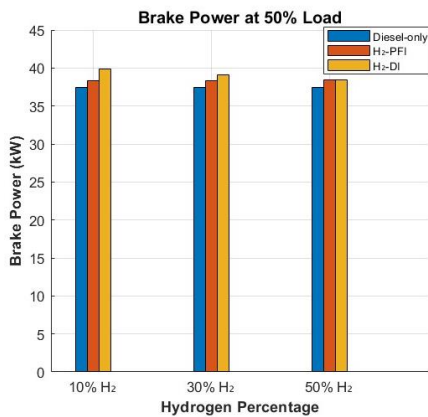


Fig 11. Comparison of BP for Diesel-only, Hydrogen PFI, and Hydrogen DI modes at 50% Load

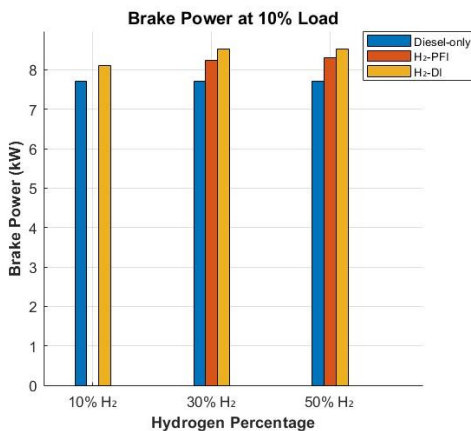


Fig 12. Comparison of BP for Diesel-only, Hydrogen PFI, and Hydrogen DI modes at 10% Load

Table 8. Comparison of Brake Power for Diesel-only, Hydrogen PFI and Hydrogen DI modes

Type	Diesel-only	H2-PFI			H2-DI		
		10% H2	30% H2	50% H2	10% H2	30% H2	50% H2
Cases	100%	10%	30%	50%	10%	30%	50%
100% Load	74.95	76.53	76.53	76.22	76.62	78.24	79.80
50% Load	37.40	38.31	38.41	38.42	38.29	39.07	39.83
10% Load	7.70	---	8.25	8.31	8.10	8.53	8.53

NO_x emissions:

In hydrogen–diesel dual-fuel modes, especially PFI, elevated in-cylinder temperatures increase NO_x formation. While hydrogen improves combustion efficiency, it also intensifies peak temperatures, thus raising thermal NO_x.

The NO_x variation for diesel-only, hydrogen–diesel dual fuel using Port Fuel Injection (PFI), and Direct Injection (DI) strategies across three engine load levels are shown in Table 9, Fig 13, Fig 14 and Fig 15.

Table 9. Comparison of NO_x Emissions for Diesel-only, Hydrogen PFI and Hydrogen DI modes

Type	Diesel-only	H2-PFI			H2-DI		
		10% H2	30% H2	50% H2	10% H2	30% H2	50% H2
Cases	100%	10%	30%	50%	10%	30%	50%
100% Load	13.68	13.67	14.12	14.95	13.26	13.17	13.28
50% Load	9.34	9.84	11.43	12.28	9.52	10.32	10.83
10% Load	8.18	---	12.21	12.6	10.08	12.04	12.41

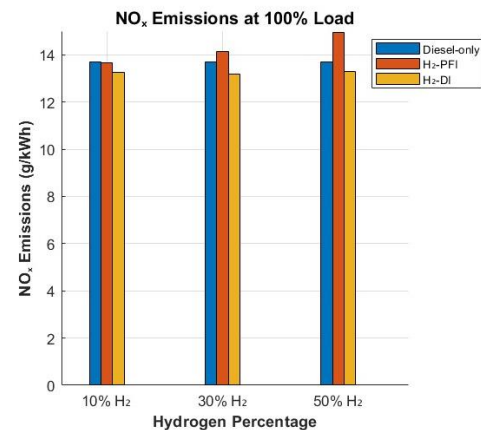


Fig 13. Comparison of NO_x for Diesel-only, Hydrogen PFI, and Hydrogen DI modes at 100% Load

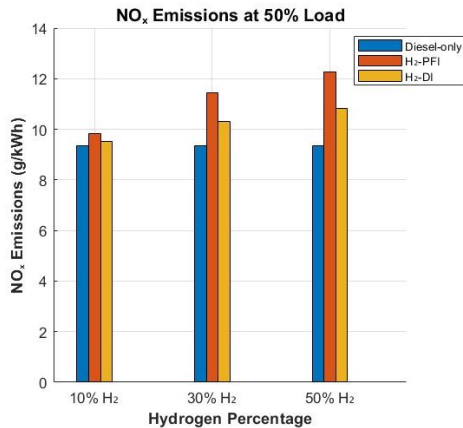


Fig 14. Comparison of NO_x for Diesel-only, Hydrogen PFI, and Hydrogen DI modes at 50% Load

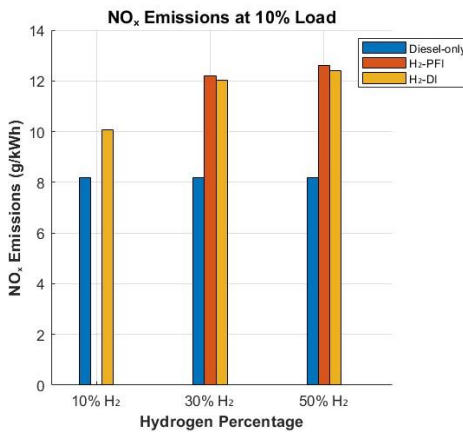


Fig 15. Comparison of NO_x for Diesel-only, Hydrogen PFI, and Hydrogen DI modes at 10% Load

In Cylinder Pressure:

The in-cylinder pressure variation for diesel-only, hydrogen– diesel dual fuel using Port Fuel Injection (PFI), and Direct Injection (DI) strategies across three engine power levels is shown in Table 10 and Fig 16.

Table 10. Comparison of Pressure for Diesel-only, Hydrogen PFI and Hydrogen DI modes

Type	Pressure (bar)						
	Diesel-only	H2-PFI			H2-DI		
Cases	100%	10% H2	30% H2	50% H2	10% H2	30% H2	50% H2
100% Load	139.3	142	147	151	144	151	156
50% Load	92.59	94	97	98	94.80	99	102
10% Load	63.19	---	64	64	63.94	65	65.6

At 10% H₂, the in-cylinder pressure curve for the hydrogen- diesel (DI) is nearly identical to that of diesel-only operation. Both curves overlap, indicating that a low level of

hydrogen addition has minimal impact on peak pressure at a crank angle of 5°. The peak pressure occurs at 5°, 3°, and 2° crank angle, respectively.

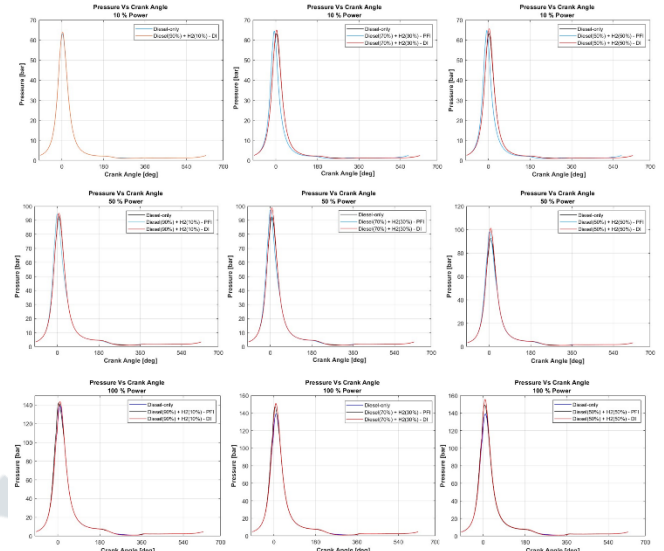


Fig 16. Comparison of Pressure for Diesel-only, Hydrogen PFI, and Hydrogen DI modes at 10%, 50% & 100% Loads

In Cylinder Temperature:

The temperature variation over the crank angle for diesel-only, hydrogen– diesel dual fuel using Port Fuel Injection (PFI), and Direct Injection (DI) strategies across different engine loads is presented in Table 11 and Fig 17.

The in-cylinder temperature profile for diesel-only and DI mode at 10% H₂ is virtually identical. With 30% H₂ The PFI shows a higher peak temperature of approximately 60°C above diesel-only). With 50% H₂ the PFI method achieves the highest peak temperature approximately 80°C higher than diesel-only.

Table 11. Comparison of Temperature for Diesel-only, Hydrogen PFI and Hydrogen DI modes

Type	Temperature (°C)						
	Diesel-only	H2-PFI			H2-DI		
Cases	100%	10% H2	30% H2	50% H2	10% H2	30% H2	50% H2
100% Load	1600	1602	1650	1700	1600	1600	1600
50% Load	1281	1282	1320	1350	1281	1281	1282
10% Load	830	---	842	858	830	840	843

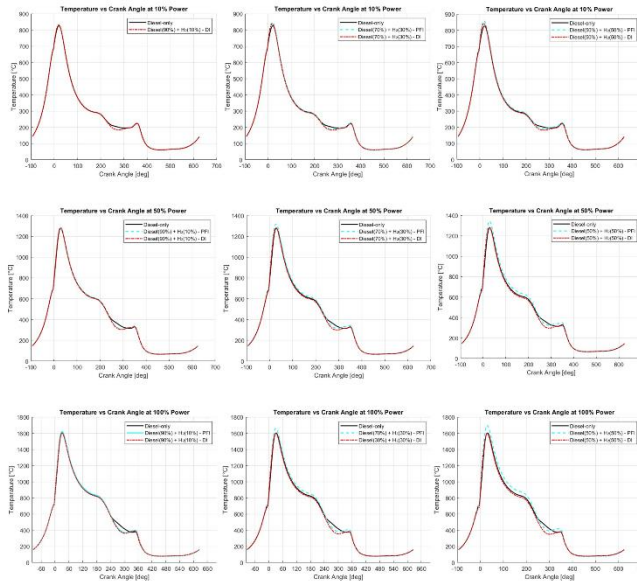


Fig 17. Comparison of Temperature for Diesel-only, Hydrogen PFI, and Hydrogen DI modes at 10%, 50% & 100% Loads

IV. CONCLUSION

The performance of a turbocharged-intercooled diesel 4-cylinder engine fueled under hydrogen–diesel dual-fuel configurations using Port Fuel Injection (PFI) and Direct Injection (DI) was investigated in this study. The effect of hydrogen substitution by hydrogen fuel (10%, 30%, 50%) on Brake Thermal Efficiency (BTE), Brake Specific Energy Consumption (BSEC), and NOx emissions was evaluated at 10%, 50% and 100% engine loads. The simulation results indicate significant performance enhancements in both dual-fuel modes compared to diesel-only operation:

The simulation results reveal that Brake Thermal Efficiency (BTE) consistently improves with increasing hydrogen substitution in both PFI and DI strategies. The improvement of the BTE show in Table 12.

Table 12. Percentage Variation of BTE compared with Diesel-only operation with PFI and DI modes

Percentage Variation when compared with Diesel-only Operation						
BTE (%)	10% H ₂ (PFI)	30% H ₂ (PFI)	50% H ₂ (PFI)	10% H ₂ (DI)	30% H ₂ (DI)	50% H ₂ (DI)
100% Load	1.63%	0.88%	0.09%	1.73%	2.92%	3.90%
50% Load	1.97%	1.39%	0.76%	1.92%	2.70%	4.00%
10% Load	—	5.50%	5.30%	4.60%	6.30%	7.90%

The simulation results reveal that Brake Thermal Efficiency (BTE) consistently improves with increasing hydrogen substitution in both PFI and DI strategies. The improvement of the BTE show in Table 13.

Table 13. Percentage Variation of BSEC compared with Diesel-only operation with PFI and DI modes

Percentage Variation when compared with Diesel-only Operation						
BSEC	10% H ₂ (PFI)	30% H ₂ (PFI)	50% H ₂ (PFI)	10% H ₂ (DI)	30% H ₂ (DI)	50% H ₂ (DI)
100% Load	2.00%	2.10%	1.60%	2.20%	4.20%	6.20%
50% Load	2.40%	2.70%	2.68%	2.37%	4.40%	6.29%
10% Load	—	6.90%	7.60%	5.12%	7.70%	10.27%

In-cylinder pressure and temperature profiles varied significantly with hydrogen substitution, influencing combustion dynamics. The increase in in-cylinder pressure with hydrogen addition is primarily due to faster, earlier, and more complete combustion.

This effect is more pronounced in DI mode due to improved combustion control, and in PFI mode due to enhanced air– fuel mixing and premixed combustion.

The temperature rise, particularly in PFI mode, explains the associated increase in NOx emissions. Overall, DI mode achieves better pressure rise control and lower peak temperatures at higher substitution rates. Due to the increase in in-cylinder temperature the formation of NOx emissions is higher compared to the diesel-only operation shown in Table 14.

Table 14. Percentage Variation of NOx emissions compared with Diesel-only operation with PFI and DI modes

Percentage Variation when compared with Diesel-only Operation						
NOx	10% H ₂ (PFI)	30% H ₂ (PFI)	50% H ₂ (PFI)	10% H ₂ (DI)	30% H ₂ (DI)	50% H ₂ (DI)
100% Load	0.73%	3.50%	9.49%	2.94%	4.43%	2.94%
50% Load	3.16%	19.05%	26.76%	1.89%	8.42%	15.79%
10% Load	—	40.00%	47.06%	22.20%	40.00%	47.00%

Overall, DI mode consistently outperformed PFI, especially at higher loads and substitution ratios, due to superior combustion control and reduced ignition delay. The increase in thermal efficiency and reduction in energy consumption make the hydrogen–diesel dual-fuel approach a viable strategy for improving engine performance and reducing fossil fuel reliance.

30% diesel substitution with hydrogen in PFI mode provided the best performance with improved brake thermal efficiency and reduced CO₂ emissions, with certain increase of NOx.

50% diesel substitution with hydrogen in DI mode achieved the highest thermal efficiency and the lowest CO₂ emissions, with certain increase of NOx.

However, a concurrent rise in NOx emissions, especially in DI mode, highlights the need for future work involving emission mitigation techniques such as EGR or after-treatment systems.

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