Journal of Advanced Engineering Research
ISSN: 2393-8447
Volume 11, Issue 1, 2024, pp.145-151

Effect on the Performance and Emission of Hydrogen Enriched Diesel in a CI Engine

Manish Kumar Singh[1,*], D.B.Lata[1], Vinay Prakash Chaudhary[1,*], Saurav Kumar[1]

[1] Department of Energy Engineering, Central University of Jharkhand, Ranchi-835222, India

*Corresponding author email: m32437069@gmail.com, vinay.20210201002@cuj.ac.in Tel. : +91 7319669246, +91 9102711879

ABSTRACT

In the last few decades, the rate of fossil fuel consumptions have increased drastically, causing severe environmental challenges. So, it is very important for us to consider of a sustainable eco-friendly alternative fuel. In such, use of hydrogen as an alternative fuel can be done due to its special properties like wide range of flammability, zero carbon content etc. This research work is based on 5% hydrogen addition in diesel at 3.5 kW rated power with a constant speed of 1500 rpm. This research is carried out on single cylinder, 4-stroke, water cooled, CRDi diesel engine at 0-80% load. The conclusion of this research was that the NOx emission increases compared to diesel fuel, but particulate matter decreases significantly. CO emission decreases with 5% hydrogen addition in diesel. NO emission decreases at low load conditions with hydrogen addition but at higher load it increases slightly. CO_2 decreases at low load condition with hydrogen addition in diesel. HC decreases at higher load with hydrogen addition in diesel, but at low load condition, it increases slightly. Brake thermal efficiency increases at higher load condition with hydrogen addition in diesel. Brake power and BSFC for 5% hydrogen addition in diesel however showed slight difference in performance at varying load conditions.

Keywords - Keywords - Diesel, Emission, Fuel, Hydrogen, Performance.

1. INTRODUCTION

Compression ignition is widely used in different sectors like transportation, agriculture, civil construction due to its high thermal efficiency, and low carbon-based emissions. However, CI engine emits high level of particulate matter and oxides of nitrogen due to combustion of heterogeneous air fuel mixture in combustion chamber. The EPA (Environmental Protection Agency) implemented CO_2 emission regulation as 820 g/kWh for light, medium and heavy–duty vehicles but on other hand side, energy efficiency is one of the important issues for sustainability of CI engine. Our current technologies like exhaust gas recirculation (EGR) retardation of injection timing is available for reduction of particulate matter emission. These available technologies are insufficient for efficiency improvement and emission reduction benefits. Use of gaseous hydrogen in CI engine as a secondary fuel is done for resolving the above issues. However, dual-fuel engines face major issues of NOX emission due to high temperature of fuel, air charge and excess oxygen concentration. It is observed in literature by many researchers that NOX emission increases with in in-cylinder temperature. It is also observed that all NOX formation occurs within 20 degree CA (crank angle) from start of combustion. Experimental investigation says that NOX emission increased from 1.8g/kWh with base diesel mode to 6.7g/kWh with use of 50% hydrogen energy share at 13% load in CI engine. This reduction is possible due to increase in fraction of water content which decreases the in-cylinder peak temperature. The combustion with hydrogen proceeds under wider range of air fuel ratios. If combustion takes place with rich air -hydrogen mixture, it results in increase of in-cylinder temperature and NOx emission formation. NOx emission in hydrogen enriched dual fuel CI engines is higher at lower speed than high speed. At high speed, NOx emission is low due to less residence time. The measurement of in-cylinder temperature at spatial coordinate in the combustion chamber is very complex. NOx emission with respect to in-cylinder temperature can be analysed with the help of CFD (Computational Fluid Dynamics). The second objective of this synopsis is assessment of maximum obtainable work which can be achieved by exergy analysis. During exergy analysis we use second law of thermodynamics. With the help of second law of thermodynamics, one can easily define the irreversibility. Irreversibility is an important parameter and with the help of this, one can estimate the maximum obtainable work. In general, irreversibility is produced in CI engines due to combustion, air fuel mixing, wall heat transfer, exhaust gas, and friction.

Table 1- Properties of diesel and hydrogen [1]–[6]

Properties	**Diesel**	**Hydrogen**
Composition(by volume)	$C_{12}H_{24}$	H_2
Calorific value(MJ/Kg)	42.5	120
Density at NTP(Kg/m3)	0.86	0.0838
Research octane number		>130
Flammability limits (vol% in air)	0.7-5	4-75
Auto-ignition temperature	553	858
Flame speed(m/s)	0.3	2.7
Cetane number	40-60	
Specific gravity	0.83	0.091
Boiling point	523-630	20.27
Stoichiometric A/F (kg of air/kg of fuel)	14.5	34

2. LITERATURE REVIEW

Edwin et al. utilised hydrogen in a CI engine and found a significant reduction in volumetric efficiency from 91% with diesel mode to 85% with dual-fuel mode (13.4% hydrogen energy share) due to displacement of air with hydrogen. The maximum reduction in the efficiency was about 6%, with 20% hydrogen substitution in the engine (49kW rated power at 1800 rpm)[7].

Liew et al. insignificant influence with low amount of hydrogen substitution but beyond 3.5 hydrogen volume share the peak pressure increased considerably. The peak pressure increased from about 110 bar with 3.5% hydrogen volume share to about 121 bar with 6% hydrogen volume share at 100 loads. However, the in-cylinder peak pressure decreased with increase in hydrogen substitution level at 20% and 40% loads. At 20% load, the pressure decreased from 53.5 bar with 0% hydrogen mass share to 49.5% bar with 29% hydrogen mass share under dual-fuel mode. Combustion process in dual-fuel engine is combined process of CI and SI engines. When hydrogen was supplied as a secondary fuel in combustion chamber during suction stroke, it mixes with air during suction and compression process and result of this high degree of homogenous hydrogen-air charge is formed[8].

Karim et al. observed that heat release rate in a dual-fuel engine have three overlapping-component. The first overlapping component is due to combustion of pilot fuel. The second component is due to combustion of gaseous fuel. The component is due to pre-ignition activity[9].

Masood et al describe the combustion concept in case of dual -fuel mode in two phases. The first phase is due to combustion of pilot fuel, while second phase is due to combustion of remaining hydrogen by flame propagation[10].

Ma et al. observed that hydrogen addition improved indicated thermal efficiency and maximum indicated thermal efficiency was obtained with ignition timings that is close to top dead centre (TDC).They also suggested that with increase in hydrogen volume percentage, ignition timing had to be retarded for optimum engine performance and lower emissions. They concluded that combustion duration may be reduced to by 1^o crank angle for every 10% (v/v) increase in hydrogen fraction and ignition delay reduction[11].

Ceper at al. observed that peak pressure increased with hydrogen energy share and the peak shifted towards TDC, with highest efficiency reported when peak pressure occurred at 10^o-15^o crank angle after top dead centre (ADTC)[12].

Deb et al. found that the addition of different amount of hydrogen energy share in intake manifold injected using an LPG-CNG injector increased BTE by 15.8% and specific energy consumption decreased by 18.6%.CO_2 emission and smoke were lowered by 39.7% and 66.2% respectively and equivalence ratio played an important role in smooth combustion process[13].

Miyamoto et al. investigated that CO_2 emission lowered by 688g/kWh with diesel fuel to 425 g/kWh by using 10% H_2 (by volume) in common rail direct injection diesel engine under dual -fuel mode[14].

Dunbar and Lior studied the irreversibility process in an adiabatic combustion chamber and found that one-third of the useful fuel energy is destroyed during combustion process[15].

Caton et al. observed that combustion irreversibility is the function of temperature, pressure and equivalence ratio and decreases with increasing combustion temperature [16].

Rakopoulos and Kyritsis stated that irreversibility is the function of fuel reaction rate which leads to decrease in irreversibility as compared to heavier molecules. He observed that the combustion process of diesel engine fuelled with H_2 (up to 10% by volume) generates less irreversibility under dual-fuel mode[18].

Taymaz et al. investigated that a diesel engine (136kW at 2400 rpm)decreases its heat transfer loss (through engine wall) from 27% without insulation to 23% with insulation. However, the heat loss increased from 24% to 27% through exhaust gases[19].

Ghazikhani et al. stated that specific fuel consumption in case of multi cylinder direct injection diesel engine (85Hp at 2800 rpm) decreases by 10% by using EGR technique. Fu et al. reported that energy efficiency is improved about 6.3% in case of four-cylinder CI engine with EGR technique[20].

Table 2- AVL 444 Specification & resolution

Measured Parameter	Specification	Resolution	Accuracy
Oxygen	0-22	0.01% Vol	0.1%Vol
CO	0-10%Vol	0.01%Vol	0.03% Vol
CO2	0-20% Vol	0.1% Vol	0.4% Vol
HC	0-20000 ppm	Upto 2000 ppm	10 ppm
NOx	0-5000 ppm	1ppm	50 ppm
Lambda	O to 9.999	0.0011	-

3. EXPERIMENTAL SETUP

The research is done on a single cylinder, four stroke, water cooled, Kirloskar diesel engine having power 3.5 kW at a constant speed 1500rpm. The diesel engine is a Common Rail Direct Injection engine. The compression ratio is taken as 18. “IC EngineSoft” engine performance is used for connecting required data. AVL 440 smoke meter is used for recording emission parameter. 5% Hydrogen enrichment in diesel is considered for the research. The performance and emission is recorded at five different load conditions: 0.2kg, 2.5kg, 5kg, 7.5kg and 10kg converted to approximately 0%, 20%, 40%, 60%, and 80% respectively.

A. Experimental Procedure

Start the IC Engine software, set the Engine and calorimeter cooling water flow rate. Now run the experimental Text Engine set up on baseline diesel at different varying loads with constant engine speed 1500rpm and fixed compression ratio 18. Now here experimental set up is rearranged for dual fuel mode condition that is baseline diesel and 5% hydrogen is used in IC Engine. Use AVL Digas Analyzer for the Emission analysis (CO_2, CO, NOX, HC, O_2) and finally start measurement of performance parameter for selected fuel.

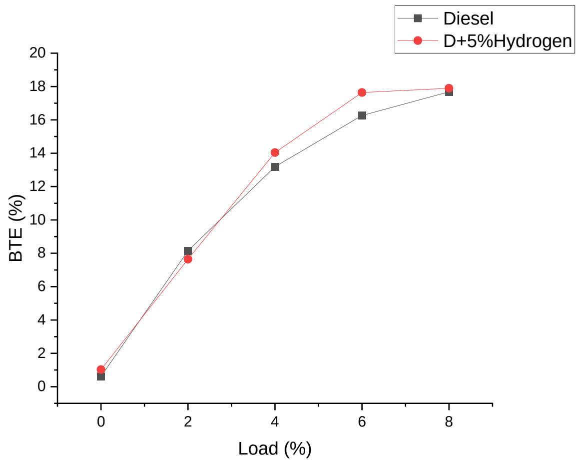
Fig 1- Pictorial view of Experimental Setup-Common Rail Direct Injection Research Diesel Engine.

Table 3- Experimental setup specifications

Product	CI Test Engine setup
Engine	Kirloskar, 3.5kW, 1500 rpm, 1 cylinder, 4 stroke, water cooled diesel engine. Stroke length 110mm, bore 87.5mm, 660cc, CR 18, Common Rail Direct injection Research Diesel Engine supported in a range of 12-18.
Dynamometer	Eddy current
Fuel tank	15L, Glass fuel metering(Burette)
Calorimeter	Pipe in pipe type
Sensors	Piezo sensor of 5000range, crank sensor with 1 degree Resolution
Temperature	Make National Instrument USB-6210
Software	“ICEngineSoft” Engine software

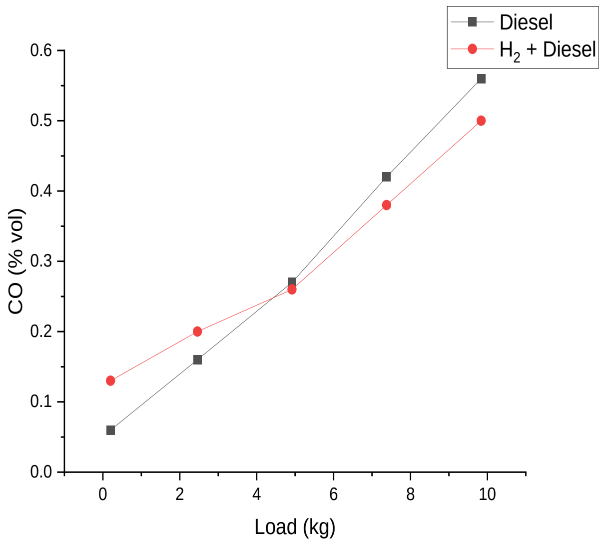
Fig 2- Setup of AVL 444 Digas Analyser with AVL 437 Smokemeter.

4. RESULTS AND DISCUSSION



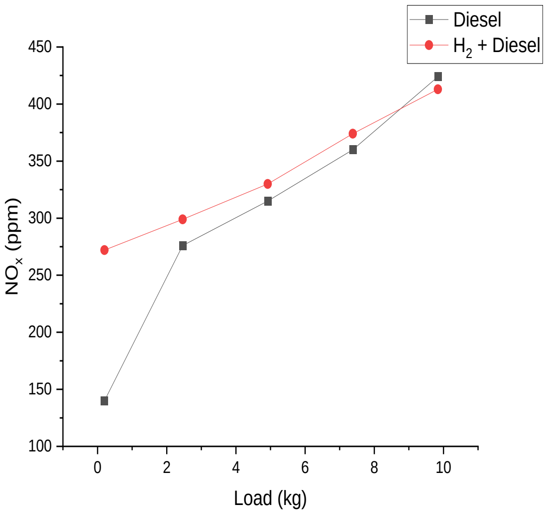
Graph 1- Effect on BTE for diesel fuel and hydrogen enriched diesel fuel at varying loads.

At 0-20 % load, 5% addition of hydrogen in diesel shows very similar result of brake thermal efficiency as in case of diesel, but at higher load, brake thermal efficiency increases at 5% addition of hydrogen in diesel in IC engine with compared to diesel fuel.



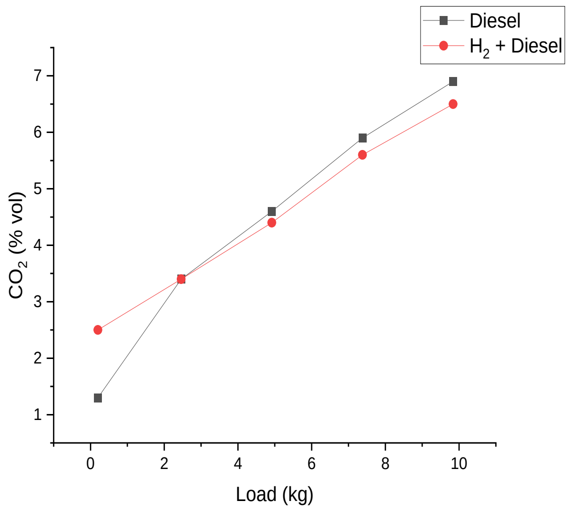
Graph 2- Effect on CO emissions for diesel fuel and hydrogen enriched diesel fuel at varying loads.

At 0-20% load percentage, volume of carbon mono-oxide emission increases at 5% addition of hydrogen in diesel compared to diesel fuel. At higher loads, carbon mono-oxide emission decreases with hydrogen (5%) enriched diesel compared to diesel fuel.



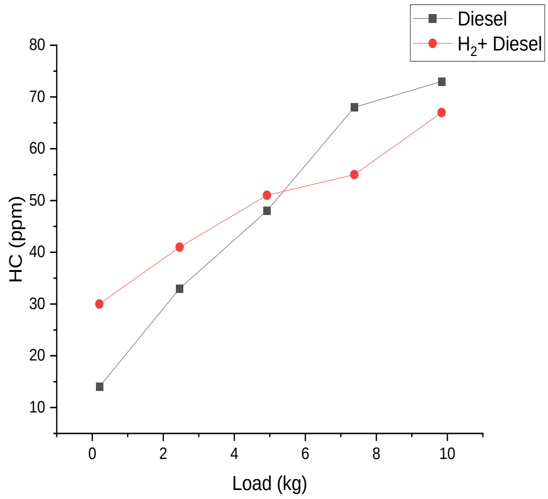
Graph 3- Effect on NO_x emissions for diesel fuel and hydrogen enriched diesel fuel at varying loads.

At 5% hydrogen addition in diesel, NO_x emission increases compared to diesel fuel in the same engine at same operating conditions of only diesel fuel used in IC engine.



Graph 4- Effect on CO_2 emissions for diesel fuel and hydrogen enriched diesel fuel at varying loads.

At 0-20% load, CO_2 emission increases with 5% hydrogen addition in diesel but in case of higher load, it decreases which is shown in graph 5.



Graph 5- Effect on HC emissions for diesel fuel and hydrogen enriched diesel fuel at varying loads.

At low conditions, HC emission increases with 5% hydrogen addition in diesel in IC engine but at higher load it decreases sharply.

5. CONCLUSION

The performance and emission analysis of IC engine operated on diesel and hydrogen in dual fuel mode indicated no major changes in exiting diesel engine. Following conclusions have been drawn by using 5% hydrogen enriched diesel in a CI engine-

1. Use of hydrogen as a secondary fuel in IC engine decreases the brake thermal efficiency at low load condition with 5% hydrogen addition, but it produces good result at higher load.
2. CO emission at 5% hydrogen addition in diesel at low load increases, but at higher load, it decreases.
3. NOx (ppm) emission at low load with 5% hydrogen used in diesel indicates the higher value, but at higher load it marginally decreases.
4. CO_2 (%Vol) emission increases at low load condition and it decreases at higher load with 5% hydrogen used in diesel for dual fuel mode.
5. HC (ppm) emission decreases at higher load with 5% hydrogen addition in diesel for dual fuel mode condition.

REFERENCE

Journal Papers:

[1] F. Tasnim, S. A. Iqbal, and A. R. Chowdhury, "Biogas production from anaerobic co-digestion of cow manure with kitchen waste and Water Hyacinth," *Renew. Energy*, vol. 109, pp. 434–439, Aug. 2017, doi: 10.1016/J.RENENE.2017.03.044.

[2] S. A. Iqbal, S. Rahaman, M. Rahman, and A. Yousuf, "Anaerobic Digestion of Kitchen Waste to Produce Biogas," *Procedia Eng.*, vol. 90, pp. 657–662, Jan. 2014, doi: 10.1016/J.PROENG.2014.11.787.

[3] P. Dimitriou and T. Tsujimura, "A review of hydrogen as a compression ignition engine fuel," *International Journal of Hydrogen Energy*, vol. 42, no. 38. Elsevier Ltd, pp. 24470–24486, 2017. doi: 10.1016/j.ijhydene.2017.07.232.

[4] J. Chi and H. Yu, "Water electrolysis based on renewable energy for hydrogen production," *Chinese J. Catal.*, vol. 39, no. 3, pp. 390–394, Mar. 2018, doi: 10.1016/S1872-2067(17)62949-8.

[5] G. H. Choi, Y. J. Chung, and S. Bin Han, "Performance and emissions characteristics of a hydrogen enriched LPG internal combustion engine at 1400 rpm," *Int. J. Hydrogen Energy*, vol. 30, no. 1, pp. 77–82, Jan. 2005, doi: 10.1016/j.ijhydene.2004.06.009.

[6] S. H. Kacem, M. A. Jemni, Z. Driss, and M. S. Abid, "The effect of H2 enrichment on in-cylinder flow behavior, engine performances and exhaust emissions: Case of LPG-hydrogen engine," *Appl. Energy*, vol. 179, pp. 961–971, Oct. 2016, doi: 10.1016/j.apenergy.2016.07.075.

[7] V. E. Geo, G. Nagarajan, and B. Nagalingam, "Studies on dual fuel operation of rubber seed oil and its bio-diesel with hydrogen as the inducted fuel," *Int. J. Hydrogen Energy*, vol. 33, no. 21, pp. 6357–6367, Nov. 2008, doi: 10.1016/J.IJHYDENE.2008.06.021.

[8] C. Liew *et al.*, "An experimental investigation of the combustion process of a heavy-duty diesel engine enriched with H2," *Int. J. Hydrogen Energy*, vol. 35, no. 20, pp. 11357–11365, Oct. 2010, doi: 10.1016/J.IJHYDENE.2010.06.023.

[9] G. A. Karim, "Combustion in gas fueled compression: Ignition engines of the dual fuel type," *J. Eng. Gas Turbines Power*, vol. 125, no. 3, pp. 827–836, 2003, doi: 10.1115/1.1581894.

[10] M. Masood, S. N. Mehdi, and P. R. Reddy, "Experimental investigations on a hydrogen-diesel dual fuel engine at different compression ratios," *J. Eng. Gas Turbines Power*, vol. 129, no. 2, pp. 572–578, 2007, doi: 10.1115/1.2227418.

[11] F. Ma, Y. Wang, H. Liu, Y. Li, J. Wang, and S. Zhao, "Experimental study on thermal efficiency and emission characteristics of a lean burn hydrogen enriched natural gas engine," *Int. J. Hydrogen Energy*, vol. 32, no. 18, pp. 5067–5075, Dec. 2007, doi: 10.1016/J.IJHYDENE.2007.07.048.

[12] N. Kahraman, B. Çeper, S. O. Akansu, and K. Aydin, "Investigation of combustion characteristics and emissions in a spark-ignition engine fuelled with natural gas–hydrogen blends," *Int. J. Hydrogen Energy*, vol. 34, no. 2, pp. 1026–1034, Jan. 2009, doi: 10.1016/J.IJHYDENE.2008.10.075.

[13] M. Deb, G. R. K. Sastry, P. K. Bose, and R. Banerjee, "An experimental study on combustion, performance and emission analysis of a single cylinder, 4-stroke DI-diesel engine using hydrogen in dual fuel mode of operation," *Int. J. Hydrogen Energy*, vol. 40, no. 27, pp. 8586–8598, Jul. 2015, doi: 10.1016/j.ijhydene.2015.04.125.

[14] T. Miyamoto, H. Hasegawa, M. Mikami, N. Kojima, H. Kabashima, and Y. Urata, "Effect of hydrogen addition to intake gas on combustion and exhaust emission characteristics of a diesel engine," *Int. J. Hydrogen Energy*, vol. 36, no. 20, pp. 13138–13149, Oct. 2011, doi: 10.1016/J.IJHYDENE.2011.06.144.

[15] W. R. Dunbar and N. Lior, "Sources of combustion irreversibility," *Combust. Sci. Technol.*, vol. 103, no. 1–6, pp. 41–61, 1994, doi: 10.1080/00102209408907687.

[16] J. A. Caton, "On the destruction of availability (exergy) due to combustion processes — with specific application to internal-combustion engines," *Energy*, vol. 25, no. 11, pp. 1097–1117, Nov. 2000, doi: 10.1016/S0360-5442(00)00034-7.

[17] C. D. Rakopoulos and D. C. Kyritsis, "Comparative second-law analysis of internal combustion engine operation for methane, methanol, and dodecane fuels," *Energy*, vol. 26,

no. 7, pp. 705–722, Jul. 2001, doi: 10.1016/S0360-5442(01)00027-5.

[18] C. D. Rakopoulos, M. A. Scott, D. C. Kyritsis, and E. G. Giakoumis, “Availability analysis of hydrogen/natural gas blends combustion in internal combustion engines,” *Energy*, vol. 33, no. 2, pp. 248–255, Feb. 2008, doi: 10.1016/J.ENERGY.2007.05.009.

[19] I. Taymaz, “An experimental study of energy balance in low heat rejection diesel engine,” *Energy*, vol. 31, no. 2–3, pp. 364–371, Feb. 2006, doi: 10.1016/J.ENERGY.2005.02.004.

[20] M. Ghazikhani, M. Hatami, D. D. Ganji, M. Gorji-Bandpy, A. Behravan, and G. Shahi, “Exergy recovery from the exhaust cooling in a DI diesel engine for BSFC reduction purposes,” *Energy*, vol. 65, pp. 44–51, Feb. 2014, doi: 10.1016/J.ENERGY.2013.12.004.