A Research on the Performance, Emission and Combustion Parameters of the Hydrogen and Biogas Dual Fuel Engine

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DOI: 10.13111/2066-8201.2020.12.3.10

Received: 02 May 2020/ Accepted: 23 July 2020/ Published: September 2020

Abstract: *In the present research a diesel engine has been converted to dual fuel mode, injecting hydrogen and biogas as secondary fuel and the tests were conducted in dual fuel mode to evaluate the performance, emissions and combustion parameters of the engine. Diesel as a pilot fuel, hydrogen and biogas as a secondary fuel were injected from the inlet manifold. The hydrogen and the biogas which is a gaseous fuel were injected at 5 liters per minute (lpm) and the tests were conducted separately. From these tests, it was noted that there is an enhancement of 27.28% in brake thermal efficiency (BTE) and increment of 10.70% in* NO_X *emissions for diesel with 5 lpm hydrogen compared with diesel fuel under single fuel mode. Also, it was noted that the reduction in BTE was around 36.50% and* NO_X *emissions about 15.68 % for diesel with 5 lpm biogas when compared with diesel fuel under single fuel mode.*

Key Words: *hydrogen, biogas, performance, emission, combustion.*

1. INTRODUCTION

In the modern lifestyle, diesel engines play a crucial role in the world due to their high fuel to power ratio, lightweight and higher efficiency [1]. But diesel fuel is diminishing rapidly and causes more environmental pollution [2]. So, most researchers are trying to replace it with

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alternative fuels. Hydrogen is one of the most promising alternative fuels due to its higher flammability, and diffusivity nature. D. Barik et al., [3] studied that better results have occurred for energy share i.e. 30.1-58.4% for biogas flow rate 0.9kg/hr compared to other flow rates in dual-fuel operations for performance, emission and combustion parameters. B. J. Bora et al., [4] performed tests on diesel engines using raw biogas as secondary fuel where the CO emission was 26.22% lower and HC emission was 41.97% lower. NO_X and CO_2 were increased by 66.65% and 27.18%, respectively. R. Chandra et al., [5] investigated the dual-fuel engine and they observed that power loss for CNG, raw biogas, and methane enriched biogas was 31.8%, 47.3% and 65.6% for converting the diesel engine into SI engine. S. R. Premkartikkumar [6] observed that by introducing hydrogen into the diesel engine decreases the brake specific fuel consumption (SFC) and increases the BTE. Also, NO_X emissions were increased and the smoke emission was decreased.

S. R. Premkartikkumar et al., [7] found that CO emission was reduced by 80% by using hydrogen and the BTE was increased for 8 lpm flow rate when compared to other flow rates of hydrogen.

P. Sharma et al., [8] examined that using hydrogen indirect injection diesel engine, the BTE was decreased by 3% at 75% load with 20% hydrogen substitution and volumetric efficiency was also decreased by 4.5% under same operating conditions under dual fuel mode.

The emissions of CO and CO_2 were reduced with an increase in hydrogen energy share under all load conditions, only NO_X was increased by 9% at 75% load with 20% hydrogen energy share. P. Dimitriou et al., [9] summarized that by using hydrogen in the CI engine, the emissions of CO, HC, CO_2, and smoke levels were reduced at optimal load.

BTE, in-cylinder temperature and the heat release rate were increased with hydrogen substitution. In EGR method, NO_X emission was decreased whereas CO, HC, and smoke were increased due to low oxygen levels inside the combustion chamber in this technique. O. H. Ghazal 2019 [10] investigated that using hydrogen in dual fuel mode the mean effective pressure increased approximately by 15%, the BTE was increased for fuel-air ratio 15-20 with hydrogen addition up to 40% and the brake power was increased by 70% for higher air-fuel ratio with 40 % hydrogen fuel substitution as compared to diesel fuel.

The emissions of CO were decreased by hydrogen substitution, whereas the CO emission was increased for air-fuel ratio less than 20. M. M. Roy el al., [11] found that by using hydrogen fuel the BTE was increased by 13% as compared to other fuels, especially for leaner operations. The CO and HC emissions were decreased; the NO_X was also decreased by about 85-90% for hydrogen fuel compared with other fuels.

V. Chintala et al., [12] summarized that using hydrogen under dual fuel mode the carbon-free carriers i.e. HC, CO, CO_2 and smoke/ particulate matter decreases at all load conditions whereas the NO_X emissions increase drastically because of high in-cylinder temperature at all load conditions.

B. Subramanian et al., [13] observed that the HHO will be improved by the systems for example, molding terminals, expanding working temperature, lessening anode dispersing, expanding the cathode surface region, expanding electrolyte focus, etc.

H. Kose et al., [14] investigated that hydrogen increases engine performance and the torque value is 344.4 Nm at critical load for H7.5 dual-fuel operations. The exhaust gas temperature was increased by properly getting together hydrogen and air which will tend to complete combustion.

The emission of O_2 was decreased in this case compared to diesel operation. V. S. Yadav et al., [15] found that by supplying 40 gm/hr. of hydrogen, the BTE was increased by 1.83% without exhaust gas recirculation technique.

The emission of NO_X was reduced at 80% load with exhaust gas recirculation technique whereas the HC, CO and CO_2 emissions were decreased at 80% load without exhaust gas recirculation technique.

2. MATERIALS AND METHODS

2.1 Hydrogen

Hydrogen is a non-metallic component that is the least difficult and lightest of the components, are regularly vapid, unscented, and exceptionally combustible diatomic gas. Hydrogen has the highest energy content per unit mass; the most looking features of hydrogen energy are highly flammable diatomic gas [16].

2.2 Biogas

Biogas is an important and accessible energy resource naturally produced from the decomposition of organic waste and it generates no net CO_2.

2.3 Engine Setup

In these present investigations, a 4-stroke single-cylinder water-cooled diesel engine with a capacity of 3.5 kW with hydro dynamometer loading was used. A hydrogen cylinder was used with a pressure of 135 bar and it releases hydrogen at 1 bar using the regulator.

A back-fire arrestor is utilized for security purposes because hydrogen is highly flammable. The gas flow was constrained by the sensor framework with a PC interface.

Fig. 1 Experimental Setup

2.4 Methodology

In the first stage, the engine was worked by an unadulterated diesel. In the second stage, the engine was worked with hydrogen and diesel under dual-fuel mode with 5 lpm hydrogen flow rate. In the third stage, the engine was worked with biogas and diesel under dual-fuel mode with 5 lpm biogas flow rate.

3. RESULTS AND DISCUSSIONS

3.1 Performance Parameters

3.1.1 BTE

Fig. 2 shows the variation of BTE at different loads for diesel, diesel with 5 lpm hydrogen and diesel with 5 lpm biogas. At all load conditions, the diesel with 5 lpm hydrogen exhibits higher BTE. The diesel with 5 lpm biogas shows less BTE at 100% load compared to the pure and diesel with 5 lpm hydrogen fuels. This is due to the fact that the higher flame speed ensures a proper combustion of the fuel and improves the BTE [17].

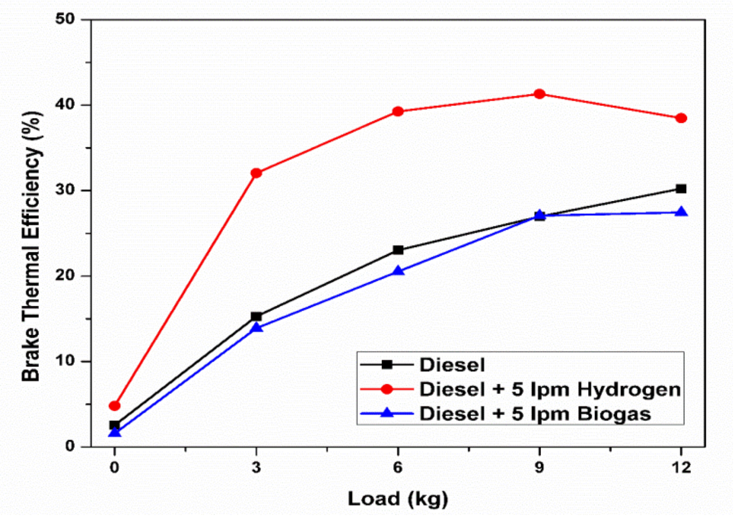

Fig. 2 BTE versus Load

3.1.2 SFC

Fig. 3 shows the variation of SFC to the loads. It was observed that the diesel with 5 lpm hydrogen shows higher SFC compared to diesel with 5 lpm biogas and diesel fuels due to the fast flame speed for hydrogen fuel. At 25% and 50% loads the fuel consumption was high because hydrogen did not easily ignite and the diesel consumption was high [18].

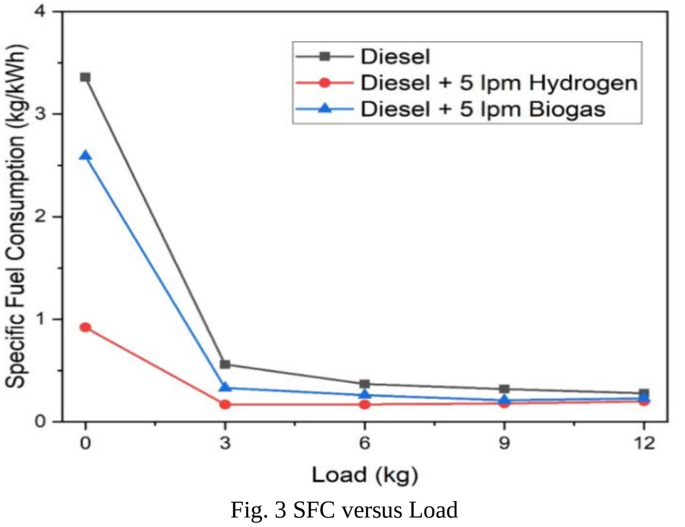

Fig. 3 SFC versus Load

3.2 Emission Parameters

The experimental tests are led on dual fuel mode using hydrogen and biogas at a 5 lpm flow rate. The emissions were estimated using exhaust gas analyser and the smoke was estimated by using a smoke meter.

3.2.1 NO_X

NO_X is subjected to combustion chamber temperature. Hydrogen is substitution under dual fuel mode; it is a highly flammable diatomic gas due to this it leads to high in-cylinder temperature. Fig.4 shows the variation of NO_X emissions with load for all operating conditions. The diesel with 5 lpm hydrogen has higher NO_X emissions compared to diesel with 5 lpm biogas and diesel fuels. The diesel with 5 lpm biogas shows lower NO_X emissions in comparison to diesel with 5 lpm hydrogen and diesel under dual fuel mode [19].

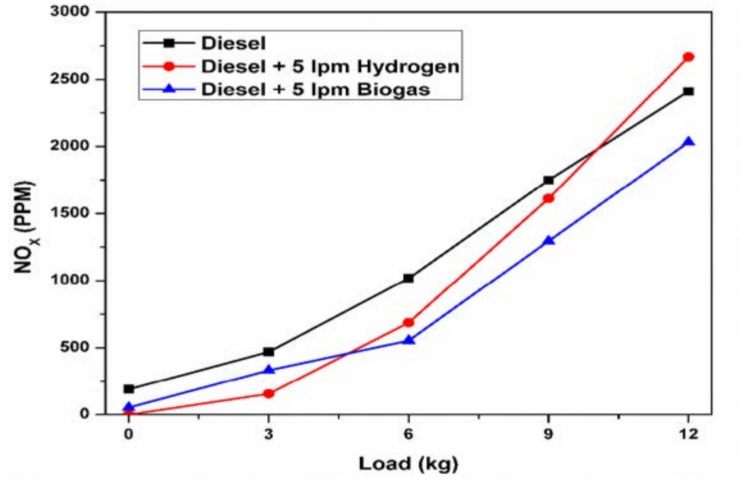

Fig. 4 NO_X emissions versus Load

3.2.2 HC

HC emissions signify the improper combustion of the fuel [20]. Fig.5 shows a comparison between HC emissions with load for diesel, diesel with 5 lpm hydrogen and diesel with 5 lpm biogas under single and dual fuel modes. The diesel with 5 lpm hydrogen shows lower HC emissions due to high burning velocity of hydrogen which increases the diesel burning compared to diesel with 5 lpm biogas and diesel fuels.

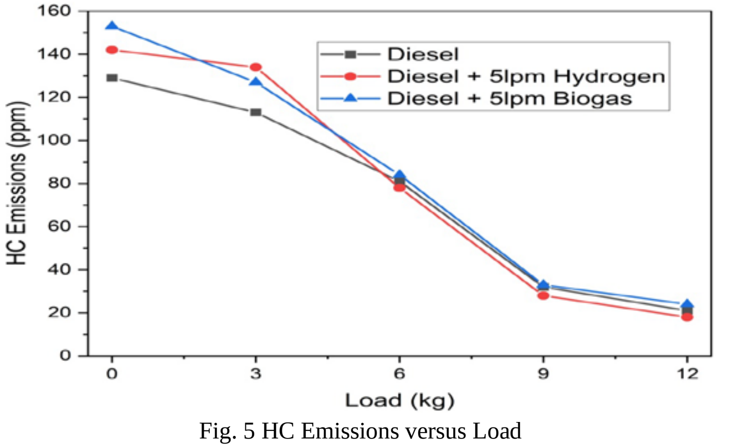

Fig. 5 HC Emissions versus Load

3.2.3 CO

Fig. 6 shows the percentage change in CO emissions with load for diesel, diesel with 5 lpm hydrogen and diesel with 5 lpm biogas under single and dual fuel modes.

The CO emissions showed decreasing with the increase of loads for all the fuel samples [21]. The diesel with 5 lpm hydrogen shows lower CO emissions when compared to diesel with 5 lpm biogas and diesel fuels.

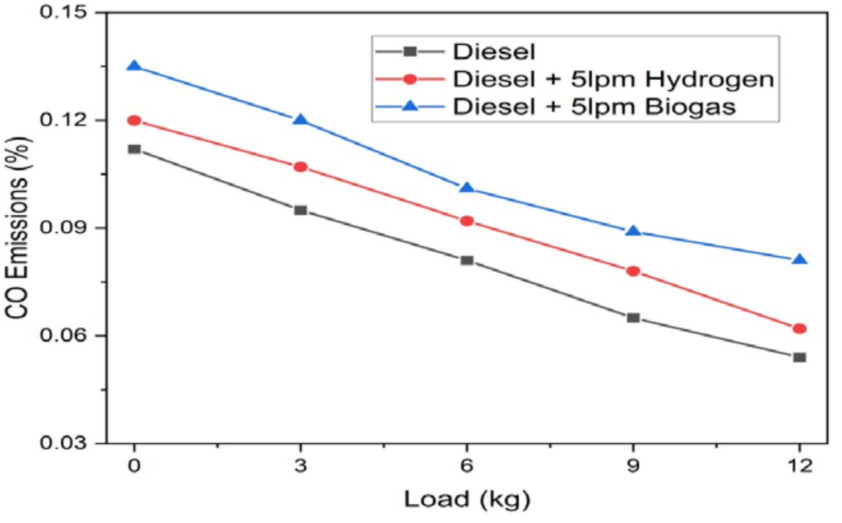

Fig. 6 CO Emissions versus Load

3.3 Combustion Parameters

At all crank angles, using pressure transducers which were connected to the diesel engine with a computer system, the cylinder pressure was measured. Fig.7 shows the crank angles with cylinder pressure. It was noticed that the diesel with a 5 lpm hydrogen sample showed high in-cylinder pressure 64.13 bar at 366°. The higher combustion rate of hydrogen fuel causes a higher temperature and pressure [22].

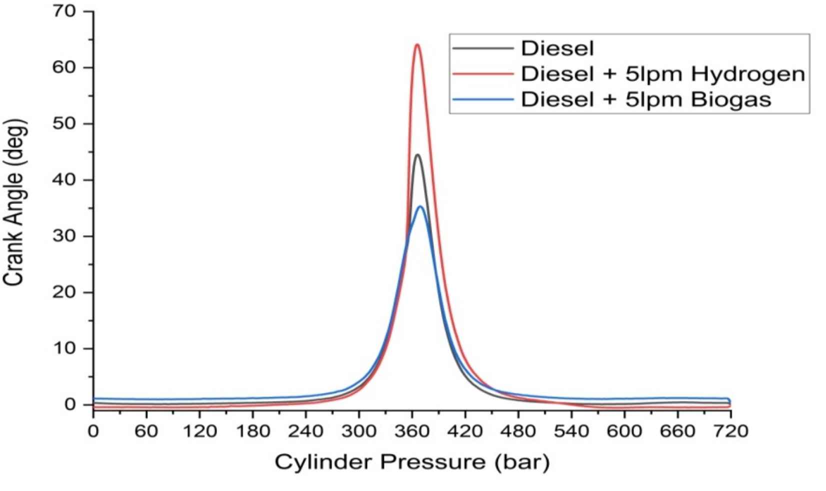

Fig. 7 Cylinder pressure versus crank angle

4. CONCLUSIONS

Initially, the engine was run with a pilot diesel fuel injection in a single fuel mode considered as basic reading. Afterwards, that engine has been converted to dual-fuel mode, by injecting hydrogen and biogas as a secondary fuel from the inlet manifold. From that experimental investigation the following conclusions were drawn:

The diesel with 5 lpm hydrogen has shown a higher brake thermal efficiency at all sorts of loads as compared to the other samples. The diesel with 5 lpm biogas has shown a significant reduction in NO_X emission compared to diesel with 5 lpm hydrogen and diesel under dual-fuel mode. It was noticed that the diesel with 5 lpm biogas has shown a high in-cylinder pressure of 64.13 bar at 366º as compared to diesel with 5 lpm biogas and diesel operations.

REFERENCES

[1] S. R. Premkartikkumar and R. K. Gopidesi, Review on effects of performance, emission and combustion characteristics of emulsified fuel in bifuel engine, *Prog. Ind. Ecol. An Int. J.*, vol. **12**, no. 1/2, pp. 59-66, 2018.

[2] R. K. Gopidesi and P. S. Rajaram, A review on emulsified fuels and their application in diesel engine, *Int. J. Ambient Energy*, https://doi.org/10.1080/01430750.2019.1667435, pp. 1–9, 2019.

[3] D. Barik and S. Murugan, Simultaneous reduction of NOx and smoke in a dual fuel di diesel engine, *Energy Convers. Manag.*, vol. **84**, pp. 217–226, 2014.

[4] B. J. Bora, U. K. Saha, S. Chatterjee and V. Veer, Effect of compression ratio on performance, combustion and emission characteristics of a dual fuel diesel engine run on raw biogas, *Energy Convers. Manag.*, vol. **87**, pp.1000-1009, 2014.

[5] R. Chandra, V. K. Vijay, P. M. V. Subbarao and T. K. Khura, Performance evaluation of a constant speed IC engine on CNG, methane enriched biogas and biogas, *Applied Energy*, vol. **88**, no. 11, pp. 3969–3977, May 2011.

[6] S. R. Premkartikkumar, Using hydrogen as a fuel in diesel engine – A Review, *International Journal of ChemTech Research*, vol. **8**, no. 8, pp. 188-193, 2015.

[7] S. R. Premkartikkumar, K. Annamalai and A. R. Pradeep Kumar, Using Hydrogen as a Fuel in Automotive Engines – An Investigation, *International Journal of Innovative Technology and Reserch*, Vol. **1**, no. 1, December-January, pp. 090-093, 2013.

[8] P. Sharma and A. Dhar, Effect of hydrogen supplementation on engine performance and emissions, *Int. J. Hydrogen Energy*, vol. **43**, no. 15, pp. 7570-7580, 2018.

[9] P. Dimitriou, T. Tsujimura, and Y. Suzuki, Adopting biodiesel as an indirect way to reduce the NOx emission of a hydrogen fumigated dual-fuel engine, *Fuel*, vol. **244**, pp. 324–334, 2019.

[10] O. H. Ghazal, Performance and combustion characteristic of CI engine fueled with hydrogen enriched diesel, *Int. J. Hydrogen Energy*, vol. **38**, no. 35, pp. 15469-15476, 2013.

[11] M. M. Roy, E. Tomita, N. Kawahara, Y. Harada, and A. Sakane, Comparison of performance and emissions of a supercharged dual-fuel engine fueled by hydrogen and hydrogen-containing gaseous fuels, *Int. J. Hydrogen Energy*, vol. **36**, no. 12, pp. 7339–7352, 2011.

[12] V. Chintala and K. A. Subramanian, A comprehensive review on utilization of hydrogen in a compression ignition engine under dual fuel mode, *Renew. Sustain. Energy Rev.*, vol. **70**, pp. 472-491, 2017.

[13] B. Subramanian and S. Ismail, Production and use of HHO gas in IC engines, *Int. J. Hydrogen Energy*, vol. **43**, no. 14, pp. 7140-7154, 2018.

[14] H. Köse and M. Ciniviz, An experimental investigation of effect on diesel engine performance and exhaust emissions of addition at dual fuel mode of hydrogen, *Fuel Process. Technol.*, vol. **114**, pp. 26–34, 2013.

[15] V. S. Yadav, S. L. Soni, and D. Sharma, Performance and emission studies of direct injection C.I. engine in duel fuel mode (hydrogen-diesel) with EGR,*Int. J. Hydrogen Energy*, vol. **37**, no. 4, pp. 3807–3817, 2012.

[16] M. A. Rahman, A. M. Ruhul, M. A. Aziz, and R. Ahmed, Experimental exploration of hydrogen enrichment in a dual fuel CI engine with exhaust gas recirculation, *Int. J. Hydrogen Energy*, vol. **42**, no. 8, pp. 5400–5409, 2017.

[17] P. Rosha, A. Dhir, and S. Kumar, In fl uence of gaseous fuel induction on the various engine characteristics of a dual fuel compression ignition engine : A review, *Renew. Sustain. Energy Rev.*, vol. **82**, no. July 2016, pp. 3333–3349, 2018.

[18] R. K. Gopidesi and S. R. Premkartikkumar, Evaluating the characteristics of a diesel engine fuelled with water in diesel emulsion and hythane gas in a dual-fuel mode, *Int. J. Ambient Energy*, pp. 1–5, 2019.
[19] H. T. Arat, M. K. Baltacioglu, M. Özcanli, and K. Aydin, Effect of using Hydroxy - CNG fuel mixtures in a non-modified diesel engine by substitution of diesel fuel, *Int. J. Hydrogen Energy*, vol. 41, no. 19, pp. 8354–8363, 2016.
[20] R. K. Gopidesi and S. R. Premkartikkumar, Performance , emission and combustion analysis of diesel engine fuelled with emulsified biodiesel, *Prog. Ind. Ecol. – An Int. J.*, vol. **13**, no. 3, pp. 292–301, 2019.
[21] R. K. Gopidesi and N. R. Gangolu, Assessment of diesel engine characteristics fuelled by jatropha with tamarind seed oil biodiesel, *INCAS Bull.*, vol. **12**, no. 1, pp. 51–57, 2020, https://doi.org/10.13111/2066-8201.2020.12.1.5.
[22] A. Sonthalia, C. Rameshkumar, U. Sharma, A. Punganur, and S. Abbas, Combustion and performance characteristics of a small spark ignition engine fuelled with HCNG, *J. Eng. Sci. Technol.*, vol. **10**, no. 4, pp. 404–419, 2015.