Sustainable Low-Carbon Combustion in Hydrogen-Assisted CRDI Diesel Engines Using Alcohol-Based Pilot Fuels for SDG-Oriented Transportation

Jibitesh Kumar Panda[1*], Mohammad Israr[2]

*[*1]Lincoln University College, Malaysia*
[2]Maryam Abacha American University of Nigeria, Hotoro GRA, Kano State, Federal Republic of Nigeria

Abstract:
This study has investigated the performance of hydrogen-assisted CRDI engine with low-viscosity alcohol pilot fuels. The existence of 20% hydrogen energy share improved the efficiency, decreased the energy consumption and exhaust emissions, and showed a practical dual-fuel strategy to support the cleaner transportation and contribute to the SDGs 7, 9, and 13.
Keywords: UN SDGs (7, 9 & 13), H_2, Pilot fuels, LVAA, Trade-off analysis.

Introduction:

The increasing concern about depletion of fossil fuels and emissions has prompted research on alternative fuels for diesel engines [1]. Hydrogen is a renewable fuel with good combustion properties and it has been proposed as a promising alternative, already being used in cars by Toyota, Honda and Hyundai [2-3]. It has high flame speed, octane number and low ignition energy which enhance the combustion, thermal efficiency and reduce fuel consumption, soot and emission [2-4]. However the effects of higher hydrogen concentrations in CRDI engines are still poorly investigated. Therefore, this work aims to investigate the performance, combustion and emissions of the CRDI engine with optimized hydrogen injection with the appropriate safety measures [5-9].

Experimental setup

The experimental setup of CRDI dual-fuel is shown in Figure 1 and the specifications are listed in Table 1. Using appropriate instrumentation, data acquisition and safety systems performance of engine, combustion and emissions were studied with hydrogen and diesel-alcohol pilot fuels under controlled operating conditions [3-5, 7-9].

Table 1: **Engine specifications:**

Details	
Product	VCR (CRDI), Kirloskar, Water coole
Bore	(87.5,110) mm, Eddy current Dynamometer
Engine	Single Cylinder, Four stroke, 3.5 kw, 1500 rpm
IP (Max)	600 bar

Energy share rate $_D = \frac{m_{hydrogen} LHV_{hydrogen}}{m_{hydrogen} LHV_{hydrogen} + m_{fuel} LHV_{fuel}}$ (1)

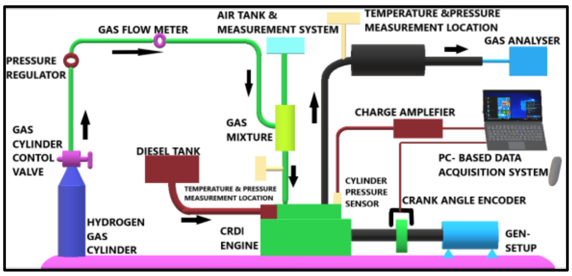

Fig.1 Line diagram for experimental investigation

Result and discussion

Combustion

Heat release rate

Figure 5 presents the variation of heat release rate with crank angle at full load. The higher hydrogen content promoted combustion and the maximum HRR was higher than that of diesel. But excess hydrogen resulted in a reduction of HRR because of oxygen deficiency, which showed better combustion performance and energy conversion efficiency [6-9].

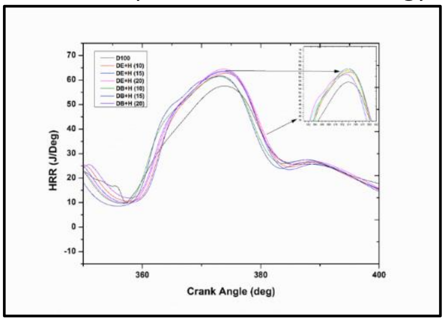

Fig.2 HRR vs Crank angel

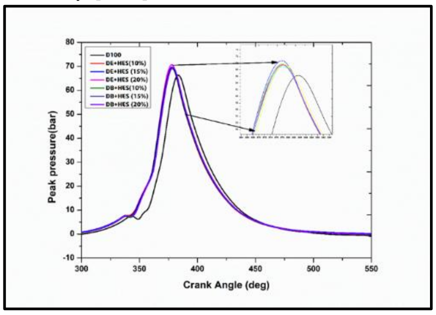

Fig.3 Pressure vs Crank angle

Cylinder pressure

The peak cylinder pressure at full load regime under hydrogen dual-fuel operation is compared in Figure 6. Hydrogen enrichment generally increased the cylinder pressure compared with neat diesel, although the higher hydrogen energy shares caused pressure reductions owing to combustion characteristics and ignition delay, consistent with previous investigations [7, 9].

Brake thermal efficiency (%)

BTE peaked at 36.83% for 20% HES with DE as shown in Figure 4 which is an increase of 36.30% over diesel. The enhanced BTE is facilitated by the high flame speed, calorific value and specific heat ratio of hydrogen. Moreover, improved homogeneity resulted in better fuel-air distribution, which led to shorter combustion time and increased efficiency, especially at high and medium loads. Use of low-viscosity alcohol additives (LVAA) in the pilot fuel also helped these efficiency gains.

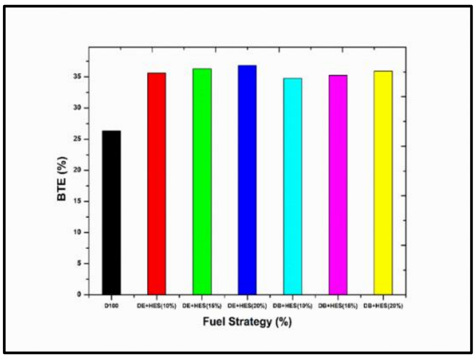

Fig.4 Fuel strategy vs BTE

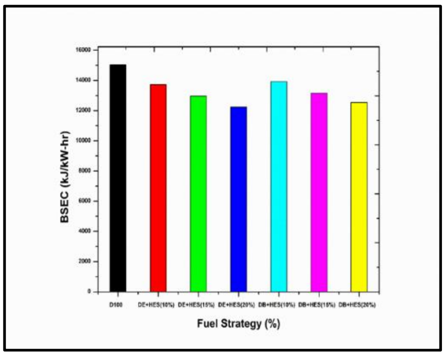

Fig.5 Fuel strategy vs BSEC

BSEC (kJ/kW-hr)

Figure 5 shows the variation of BSEC with brake power using Eq. (3). Hydrogen enrichment reduced BSEC, with DE+HES (20%) showing the greatest improvement because of enhanced combustion, air-fuel mixing, and rapid flame propagation [6-9].

Emission

Unburned hydrocarbon (PPM)

Figure 10 demonstrates that hydrogen enrichment reduced UHC emissions by improving oxidation and combustion efficiency. Compared with conventional diesel, hydrogen-fueled operation produced substantially lower UHC emissions at full load, consistent with earlier studies [2-5].

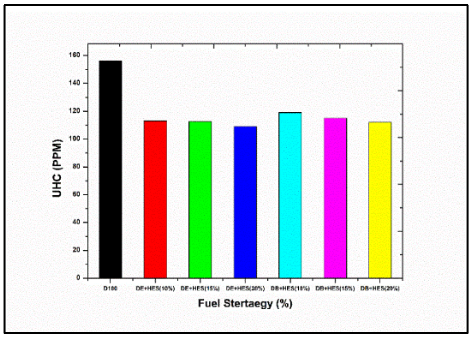

Fig.6 Unburnt hydrocarbon

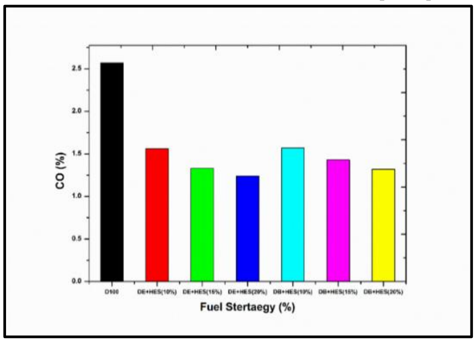

Fig.7 Carbon Monoxide

Carbon monoxide (%)

Figure 7 shows CO emissions of various fuel combinations. Hydrogen enrichment greatly reduced CO emissions compared to the conventional diesel operation, due to improved combustion and faster CO oxidation, and proved to be more beneficial, as confirmed by the findings of previous studies [4-7].

Carbon dioxide (%)

The CO_2 emissions for different shares of hydrogen energy are given in Fig. 8. Hydrogen enrichment significantly reduced the CO_2 emissions compared to the use of neat diesel by decreasing the carbon input and increasing the combustion efficiency, as reported in previous studies [9].

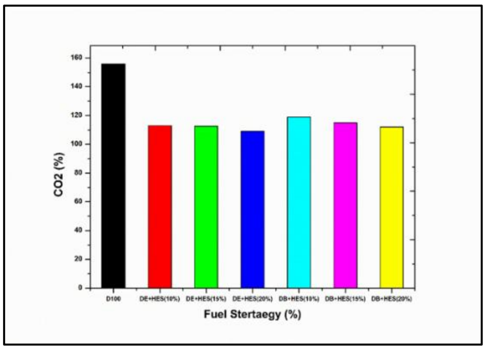

Fig.8 Carbon dioxide

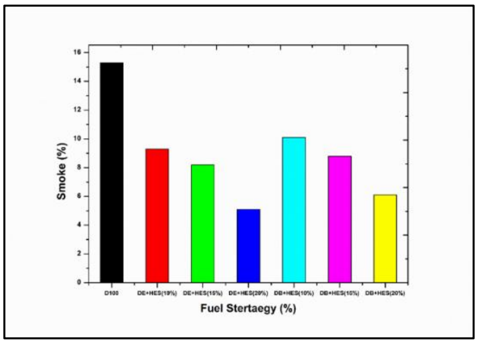

Fig.9 Smoke

Smoke (% of opacity)

Figure 9 shows the smoke emissions under the hydrogen enriched operation. The use of hydrogen showed significant reduction of smoke with respect to neat diesel due to absence of carbon-based soot formation and improved combustion. The best share of hydrogen energy gave the lowest emissions, in accordance with previous studies [3-6].

Economic and environmental aspects

Figure 10: Cost and performance of different fuel strategies. DE+HES (20%) provided the best combination of fuel economy, brake thermal efficiency and operating cost and was superior to conventional diesel and other dual-fuel combinations [4-7].

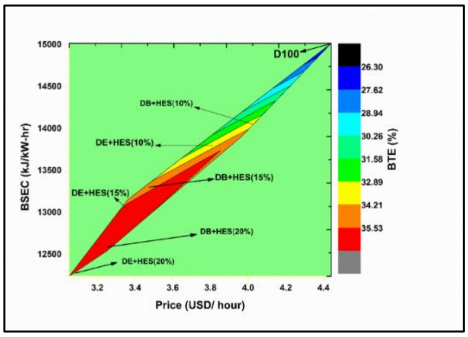

Fig.10 Economical vs Performance

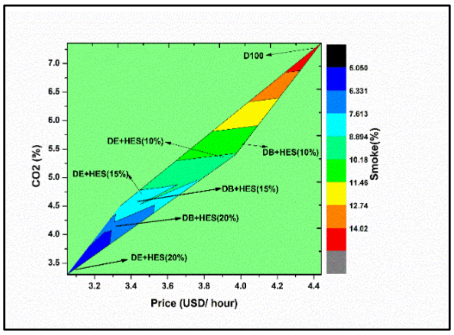

Fig.11 Economical vs Emissions

Hydrogen offers a cleaner alternative fuel by lowering carbon emissions and enabling flexible dual-fuel operation with diesel and alcohol additives. The trade-off analysis (Fig. 11) identified DE+HES (20%) as the optimum combination, providing the best balance of cost, efficiency, and reduced smoke and CO_2 emissions [3-9].

Conclusion:

This paper deals with the effect of hydrogen enrichment on combustion, performance and emission characteristics of a dual fuel CRDI diesel engine.

- A 20% hydrogen energy share increased brake thermal efficiency by 36.83% and reduced brake-specific energy consumption by 19.48%.
- Hydrogen enrichment improved combustion, reducing smoke (51.5%), CO_2 (47.9%), CO (46.2%), and HC (39.3%).
- DE+HES (20%) achieved the lowest fuel cost ($3.05) compared with neat diesel ($4.44).
- Trade-off analysis identified DE+HES (20%) as the optimum fuel strategy, offering the best balance of efficiency, cost, and emissions.

References:

[1] S. Javed, Y. V. V. Satyanarayana Murthy, R. U. Baig, and D. Prasada Rao, “Development of ANN model for prediction of performance and emission characteristics of hydrogen dual fueled diesel engine with Jatropha Methyl Ester biodiesel blends,” *J. Nat. Gas Sci. Eng.*, vol. 26, pp. 549–557, 2015, doi: 10.1016/j.jngse.2015.06.041.

[2] Y. Karagöz, I. Güler, T. Sandalci, L. Yüksek, and A. S. Dalkiliç, “Effect of hydrogen enrichment on combustion characteristics, emissions and performance of a diesel engine,” *Int. J. Hydrogen Energy*, vol. 41, no. 1, pp. 656–665, 2016, doi: 10.1016/j.ijhydene.2015.09.064.

[3] C. S. Aalam, C. G. Saravanan, and B. P. Anand, “Impact of high fuel injection pressure on the characteristics of CRDI diesel engine powered by mahua methyl ester blend,” *Appl. Therm. Eng.*, 2016, doi: 10.1016/j.applthermaleng.2016.05.176.

[4] H. H. Masjuki, A. M. Ruhul, N. N. Mustafi, M. A. Kalam, M. I. Arbab, and I. M. Rizwanul Fattah, “Study of production optimization and effect of hydroxyl gas on a CI engine performance and emission fueled with biodiesel blends,” *Int. J. Hydrogen Energy*, vol. 41, no. 33, pp. 14519–14528, 2016, doi: 10.1016/j.ijhydene.2016.05.273.

[5] I. T. Yilmaz, A. Demir, and M. Gumus, “ScienceDirect Effects of hydrogen enrichment on combustion characteristics of a CI engine,” Int. J. Hydrogen Energy, pp. 1–11, 2017, doi: 10.1016/j.ijhydene.2017.01.214.

[6] M. A. Akar, E. Kekilli, O. Bas, S. Yildizhan, H. Serin, and M. Ozcanli, “Hydrogen enriched waste oil biodiesel usage in compression ignition engine,” *Int. J. Hydrogen Energy*, vol. 43, no. 38, pp. 18046–18052, 2018, doi: 10.1016/j.ijhydene.2018.02.045.

[7] V. Gnanamoorthi and N. M. Mohandoss, “Environmental Effects Combustion , performance and emission analysis of dual fuel engine using tsrb biogas,” Energy Sources, Part A Recover. Util. Environ. Eff., vol. 00, no. 00, pp. 1–13, 2018, doi: 10.1080/15567036.2018.1550538.
[8] S. Tayari and R. Abedi, “Effect of Chlorella vulgaris methyl ester enriched with hydrogen on performance and emission characteristics of CI engine,” Fuel, vol. 256, no. July, p. 115906, 2019, doi: 10.1016/j.fuel.2019.115906.
[9] S. Ouchikh, M. S. Lounici, L. Tarabet, K. Loubar, and M. Tazerout, “Effect of natural gas enrichment with hydrogen on combustion characteristics of a dual fuel diesel engine,” *Int. J. Hydrogen Energy*, vol. 44, no. 26, pp. 13974–13987, 2019, doi: 10.1016/j.ijhydene.2019.03.179.