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Studies on Biodiesel and Hydrogen Powered Dual Fuel Common Rail Direct Injection Engine

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Abstract

Objectives: To evaluate the effect of hydrogen (H_2) and used temple oil biodiesel (BTO) combination on the performance of Common Rail Direct Injection (CRDi) engine. To report the maximum possible H_2 flow rate (HFR) for knock free operation of the engine at a speed of 1500 RPM. **Methods:** Transesterification process was used to get BTO. H_2 was inducted through intake manifold. BTO was injected into engine cylinder using electronically controlled technique. **Findings:** The study revealed that the peak HFR was $0.25 Kg/h$ for BTO and 0.24 Kg/h for diesel at an Injection Pressure (IP) of 800 bar and Injection Timing (IT) of 9° before top dead center (bTDC). The Dual Fuel (DF) CRDi engine with Toriodal Reentrant Combustion Chamber (TRCC) shape yielded 6% to 7.5% lower Brake Thermal Efficiency (BTE) with reduced exhaust gas emissions except 19 to 24% higher oxides of nitrogen (NOx) at 75% and 100% loads. Both Peak Combustion Pressure (PP) and Heat Release Rate (HRR) were 5 to 9% higher than BTO run diesel engine operation. Combustion Duration (CD) and Ignition Delay (ID) were 6 to 15% lower in DF CRDi operation with H_2. **Novelty:** Diesel engine comes with hemispherical combustion chamber (HCC). Toriodal Reentrant Shaped Combustion Chamber (TRCC) was adopted in place of HCC which results better mixing of air and fuel. H_2 and BTO combination was used to power CRDi engine. Electronically controlled fuel injection system developed and fitted to conventional diesel engine.

Keywords: Used temple oil biodiesel (BTO); Common rail direct injection (CRDi) engine; Toriodal reentrant combustion chamber (TRCC); Hydrogen flow rate (HFR); Hydrogen-biodiesel energy ratio (H_2BER)

1 Introduction

The sustainable development goals set steps towards zero carbon emission. Diesel engines have advantages as well as disadvantages, so to address disadvantages like higher emissions, CRDi engine is a good candidate and same was tested in various studies.

CRDi engine use electronically controlled fuel injection technique. A review work highlights on performance of CI engine. Lower BTE and exhaust gas combustion temperature (EGT) were reported between values of 2 to 22% with 36%, 23% and 30% higher BSFC, PP and HRR respectively when gaseous fuel used in dual fuel mode. Analysis of emission revealed that smoke and NOx reduced between 20 and 60% while HC and CO increased up to 30%[1]. A study reviews H_2 usage in vehicles and the state-of-the-art experimental work with H_2. It is reported that increase of engine power and torque in petrol run engines while reverse trend in LPG and diesel run engines when the amount of H_2 added increased. Lower harmful emissions in gasoline and LPG run engines while more NOx in diesel run engines reported. Overall, it is said that H_2 usage in all engine types is environment friendly[2]. A review work reported that H_2 is the best renewable fuel to run engines as it drastically enhances the performance besides yielding very low emissions. But also highlighted that engine has higher NOx emissions and lower power output[3,4]. A work reported percentage decrease in diesel consumption is approximately 0.6× hydrogen energy share (HES). The increase in NOx with HES was about 1.5 2.0 times[5]. Pumpkin-maize (PM) biodiesel and diethyl ether (DEE) were blended and used in a work. B20 blend boosts BTE by 31.91% and decreases BSFC by 9.519%, NO by 34.91%[6]. The preheated blend (Neem oil with 5% Ethanol) exhibited better performance in comparison with solely unheated diesel or unheated blend[7]. For both 450 bar and 650 bar fuel IP in CRDi engine, NOx increased slightly as the biodiesel fraction in the fuel blend increased[8]. As the energy share of CNG increased from 0% to 95%, increase in ID and reduction in CD was reported. Increase in NOx, PP and HRR was revealed with CNG gas energy share[9]. A study on IC engines with H_2 as a fuel showed lower torque, power, BTE, CO, UHC, CO_2 and soot with increase in BSFC and NOx[10,11]. A work showed that increase in HES lowers BTE and increases BSFC. This work also reported that increase in HES could reduce harmful emissions at low and mid loads[12]. A research work with variation in H_2 revealed lower smoke, higher BTE and NOx. For higher H_2 flow rate, delay in OH radical increased ID[13]. A study showed that hydrogen-biogas-diesel fuel combination enhanced performance in terms of lower emissions and higher BTE (3.09%) with lower BSFC (12.13%)[14]. Enrichment of H_2 enhances combustion and resulted 2.5% and 1.6% increase in BTE of diesel and biodiesel respectively. The H_2 addition showed 4- 38% reduced CO and $6-14\%$ reduced HC[15]. The magnitude of H_2 fraction is limited due to knock[16]. A work reported that 2 pilot and 1 post injection strategy lowered smoke as compared to 1 pilot strategy adopted and in all cases NOx increased. A significant increase in engine power was observed with this approach[17]. The fuel IP was varied (400 bar, 500 bar and 600 bar) in the analysis of CRDi engine performance. CO, HC, and smoke were lowered with IP and NOx elevated with IP. But not much variation in BTE and SFC was reported[18]. In a work at 90MPa, NOx, HC, and CO in CRDi engine were decreased by 28%, 18.5% and 17% respectively. EGR decreased BTE about 14.2% and lowered HC, CO, and NOx by 6.3%, 9% and 30.5% respectively[19]. The oil from temples (Mixture of edible and non-edible oils) either goes waste or used for human consumption. If used for human consumption, it leads to health issues. So, if same is converted to biodiesel and used to power diesel engine makes sense to avoid issues of human health besides revenue generation for temples. Conventional HCC is replaced by TRCC as it enhanced the mixing of air and fuel thereby better results. An exhaustive review of the literature reports that the use of H_2 induction along with BTO injection combination in DF CRDi mode is not tested for maximum possible H_2 flow rate (HFR) with toriodal reentrant combustion chamber (TRCC) shape. Hence, this work is an attempt to report the performance of DF CRDi engine operated with BTO and H_2 fuels with TRCC.

2 Material and methods

2.1 Fuels of study

In this work, H_2 was inducted through inlet manifold and BTO injected into cylinder using 7-hole injector. Physicochemical characteristics of diesel, BTO and H_2 are given in Tables 1 and 2.

Table 1. Attributes of the tested fuels

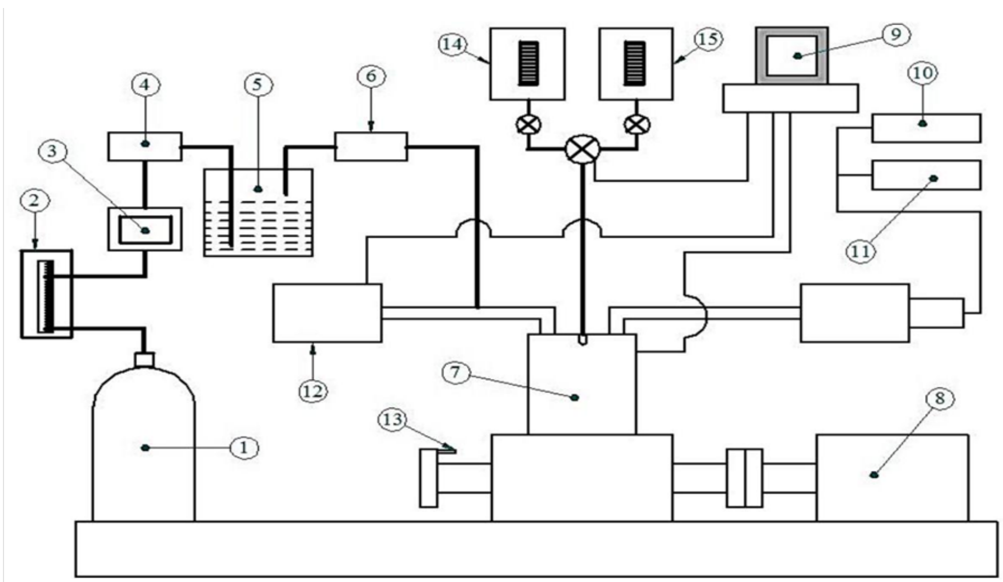
Attributes	Diesel	BTO	ASTM standard
Viscosity (cSt at 313 K)	2.5	5.1	ASTM D445
Flash point (K)	323	437	ASTM D93
Calorific Value (MJ/kg)	45	39.08	ASTMD586
Density $\left(kg/m^3\right)$ at 288 K)	831	860	ASTMD4052
Cetane Number	$45-55$	41	ASTM D613
Cloud Point (K)	271	273	ASTM D2500
Pour Point (K)	268	278	ASTM D97

Table 2. Properties of H_2 [20–22]

Properties	Values
Self-ignition temperature (K)	858
Lowest ignition energy (mJ)	0.02
Flammability Limits (% vol. in air)	4 to 75
Stoichiometric air fuel ratio (AFR) on mass basis	34.3
Density at 288 K	0.0838
Calorific value (GJ/kg)	0.11993
Flame velocity (m/s)	2.65 to 3.25
Octane number	130

2.2 Diesel Engine used

The tests were planned keeping compression ratio (CR) of 17 and IP of 800 bar. The 3.75 kW diesel was connected to a dynamometer. The line diagram of engine setup is provided in Figure 1. A piezoelectric type pressure pickup gave pressure. The HRR was calculated based on 100 cycles[23,24]. The results reported in the work are based on the average of 3 trials.



1) Hydrogen Cylinder, 2) Rota meter, 3) Glass Flow meter, 4) Inline flame trap, 5) Flame Trap (wet), 6) Flame Arrester (dry), 7) Diesel Engine, 8) Eddy current dynamometer, 9) PC interfaced engine, 10) Exhaust gas analyser, 11) Smoke meter, 12) Air box, 13) Proximity sensor, 14) Diesel tank, 15) Biodiesel tank.

Fig 1. Engine used in dual fuel mode

2.3 Uncertainties in the measured and calculated analysis

The uncertainties in the measured and calculated values at typical operating condition are given in Table 3.

Table 3. Uncertainties in the measured and calculated values

Measured variable	Accuracy ($\pm$)
Load, N	0.1
Engine speed, rpm	4
Temperature, $^{\circ}C$	2
Measured variable	**Uncertainty (%)**
Smoke	$\pm$1.3
HC	$\pm$1.6
CO	$\pm$2.4
NOx	$\pm$5
Calculated parameters	**Uncertainty (%)**
BTE, (%)	$\pm$1.1

3 Results and Discussion

H_2 supply increased till knock free operation was possible at 75% and 100% loads only, keeping CR of 17. Equation (i) was used to find H_2 fuel energy ratio (HFER).

$$Hydrogen\ fuel\ energy\ ratio = \frac{(EC_{Hydrogen})}{EC_{Hydrogen} + EC_{LF}} \tag{i}$$

3.1 Effect of H_2 induction

- **Brake Thermal Efficiency (BTE)**

BTE at 75% and 100% engine loads is given in Figure 2. Diesel and BTO injected at 23 ° bTDC in CI mode gave better BTE as compared to CRDi mode where fuel was injected at 10 $^{\circ}bTDC$ along with H_2 induction. H_2 supply stopped at $0.25 Kg/h$ for BTO and $0.24 Kg/h$ for diesel run operation as engine started knocking beyond the same. BTO, H_2 - BTO fueled tests gave little lower BTE as compared to diesel operations. Higher viscosity might be the reason. For maximum HFR at both loads, the CRDi engine showed 6% to 7.5% reduced BTE with BTO in comparison with CI approach. Similar results reported in review articles[10,11].

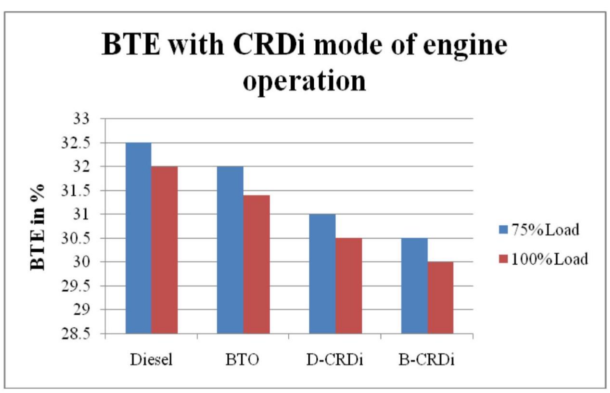


Fig 2. BTE with CRDi mode of engine operation

- ***HC* and *CO* emission**

Figures 3 and 4 illustrate the impact HFR on CRDi engine HC and CO at 75% and 100% respectively. BTO run CI and CRDi operations showed little higher emissions in contrast to diesel. CRDi engine showed lower emissions as HFR increased up to 0.25 kg/h and stopped H_2 supply beyond this level due to engine knock. These trends would be owing to the enhanced mixture

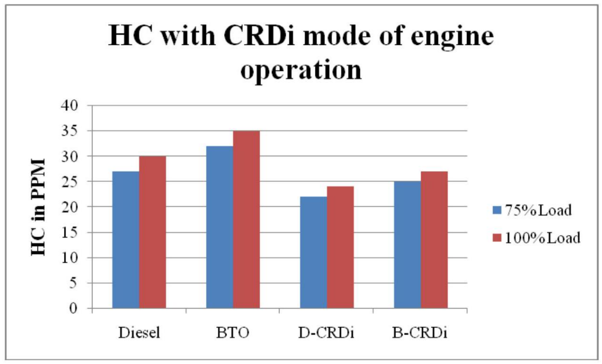


Fig 3. HC with CRDi mode of engine operation

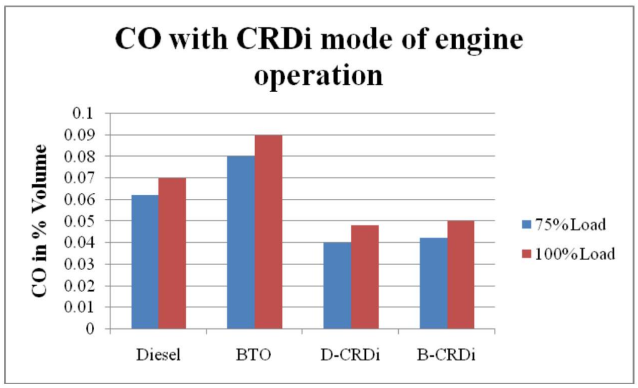


Fig 4. CO with CRDi mode of engine operation

burn rate with higher PP and HRR. The H_2 has faster flame speed and reaches CC wall in lesser milliseconds and lead to whole fuel burning, so lower HC and CO. Use of TRCC shape may be the other reason. Literature[15,19] reported the same trends.

- NO_x **emission**

NOx composed predominantly NO and NO_2 and its level depend on oxygen level, temperature and reaction residence time in CC. Figure 5 depicts the NOx at 75% and 100% loads. The NOx level in CRDi mode is 40 to 45% lower than CI mode. CRDi mode show decreased NOx in comparison with CI mode due to less combustion temperature and residence time of gas in CC. Also, combustion starts late in CRDi operation than CI mode as fuel was injected late. Similar results could be seen in literature[14,19]. BTO showed NOx of 2 to 4% higher than diesel in both modes.

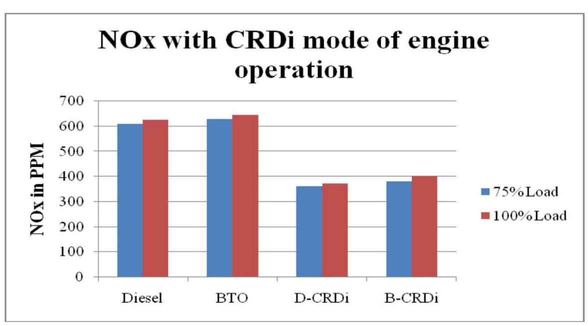


Fig 5. NOx with CRDi mode of engine operation

- **Combustion characteristics**

Figures 6 and 7 shows PP and ID obtained respectively at 75% and 100% loads. In dual fuel (DF) CRDi operation, PP and HRR reported are higher in CRDi mode than CI mode where ID values are lower because of higher H_2 flame speed that led to fast combustion. Literature[13] supports for the same. BTO showed little lower HRR and PP than diesel and on contrary little higher ID in both modes. This could be due to higher viscosity and flash point of BTO.

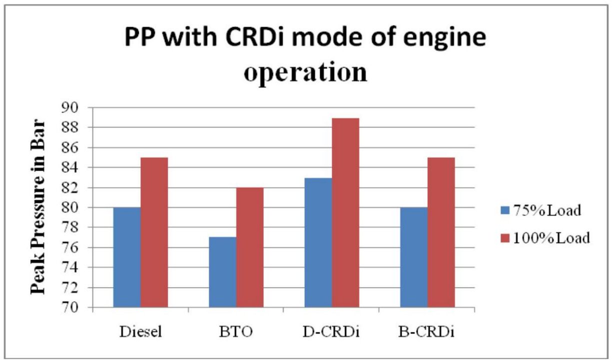


Fig 6. PP with CRDi mode of engine operation

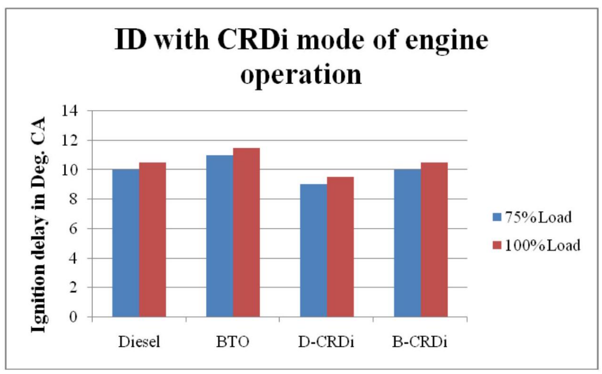


Fig 7. ID with CRDi mode of engine operation

4 Conclusions

In the present work, DF CRDi engine performance was investigated with BTO and H_2. The work concludes and recommends the followings based on the study:

- H_2 use saves liquid fuel. DF CRDi engine operation at CR - 17, maximum HFR and TRCC profile gave lower emissions with little compromise in BTE.
- DF CRDi engine yielded 6% to 7.5% lower BTE and 25% to 39% smoke with TRCC in comparison to CI mode.
- NOx in DF CRDi mode was 40 to 48% lower due to low gas temperature.
- Both PP and HRR were 5 to 9% higher in DF CRDi operation than CI mode.
- Both ID and CD were 6 to 15% lower in DF CRDi operation than CI mode.

To conclude, DF CRDi engines run smoothly with BTO and H_2 induction. The use of BTO and H_2 in CRDi engine would provide total freedom from diesel with lower harmful emissions. The use of BTO also increases the revenue for temples besides providing a solution to human health issues that could arise on its consumption. Hence, this work recommends the use of fuels selected in combination to address the shortage issue of fossil fuel and keep environment free from pollution.

5 Nomenclature

IP - Injector opening pressure; bTDC - Before top dead center; BTE - Brake thermal efficiency; H_2 - Hydrogen; HFR - Hydrogen flow rare; TRCC - Toriodal Reentrant Combustion Chamber; NOx - Oxides of nitrogen; ID - Ignition delay; BSFC - Brake specific fuel consumption; HRR - Heat release rate; IT - Injection timing; CO - Carbon monoxide; HC - Hydrocarbon; CNG - Compressed Natural gas; CD - Combustion duration; PP - Peak pressure

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