Fuel 222 (2018) 852–858

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Full Length Article

Compression ratio influence on combustion and emissions characteristic of hydrogen diesel dual fuel CI engine: Numerical Study

Priybrat Sharma, Atul Dhar*

School of Engineering, Indian Institute of Technology Mandi, Mandi 175005

ARTICLE INFO

Keywords:
Hydrogen
Dual-fuel mode
Knock
Low-Temperature Combustion
Combustion
Emissions

ABSTRACT

The effect of compression ratios variation on maximum potential hydrogen energy share in a dual fuel engine is studied by creating a numerical model for engine combustion and emission characteristics. Hydrogen is induction through the intake port, using port fuel injector (PFI). Compression ratio is varied in steps of 14.5, 16.5 and 19.5 in all the investigations. Hydrogen energy share variation ranged from 0% to 55%. The results show a clear trade-off between maximum hydrogen energy share and compression ratio. Knock limited maximum hydrogen energy share increased from 20% to 45% as compression (CR) is decreased from 19.5 to 14.5. At all compression ratios as the energy proportion of hydrogen is increased, emissions other than NOx show an apparent decline.

1. Introduction

Superior fuel economy, higher low-end torque, and durability makes diesel engine ubiquitous in transport and hauling scenarios. Still, diesel engines are plagued with higher soot and NOx emissions, which can be attributed to the heterogeneous nature of conventional diesel combustion [1]. Bringing the emissions down and increasing combustion efficiency has been an ever going quest in the field of Internal combustion engines. Over the years, complex and diverse technologies have emerged for addressing the issues with conventional diesel combustion. Some of such technologies are LTC, HCCI, PCCI and RCCI [2]. However, most of these technologies do not target the existing in-service engines and require specialised engines, which are designed to offer more combustion control. Where else, dual fuel approach provides a small implementation cost alternative for improving combustion efficiency in a conventional diesel engine, as it requires minimal engine modification [3,4].

With growing stress on traditional fuel sources, the push has been towards the use of renewable or alternative fuel resources to meet the ever-growing need for energy. Use of alternative fuel sources not only shows promising results in reducing the stress on conventional fuel resources but also decreases the financial burden on the countries dependent on petroleum imports. Hydrogen, amongst such fuels, is highly sought after due to its clean burning nature and possible renewable energy based production route.

In recent years, substantial advancement has been brought forth in the application of hydrogen as fuel, both as a secondary as well as primary fuel in internal combustion engines. Supplementation of hydrogen as a secondary fuel in diesel fuelled compression ignition engine has been widely experimented in the recent decade and strides have been made in increasing the hydrogen share in dual-fuel engines. These improvements come from increased control over the combustion and combustion phasing through better fuel injection strategies. Hydrogen has many advantages when used as fuel in internal combustion engine due to its properties [5–7], Table 1 compares essential combustion related properties of hydrogen to that of diesel.

High diffusivity of hydrogen, allows perfect premixing with air when port injection. Such premixing reduces the heterogeneous nature of CDC making the charge inside the cylinder more uniform. Hydrogen addition shows an increase in thermodynamic efficiency when burned along with slow burning fuels like diesel due to higher flame speed. Wide flammability limits of hydrogen (4- 74% by volume) can allow for low-temperature combustion (LTC) in leaner mixtures. These properties lead to low hydrocarbon and carbon monoxide emissions when used alongside with other fuels [4–6,8–10]. Auto-ignition temperature of hydrogen is 576°C, which is comparatively high, making ignition of hydrogen only by compression impossible. In the case of dual fuel engines, diesel acts as an ignition source for the hydrogen [11]. The significant difficulties presented by hydrogen when used in neat form are long auto-ignition delay and high-pressure rise rate[12].

V. Chintala et al. [13] reported that maximum hydrogen energy share with knock free operation is 19% under a compression ratio of 19.5:1 and it grows to 59% and 63% with compression ratios of 16.5:1 and 15.4:1 respectively. Thermal efficiency shows improvement as

---

* Corresponding author.
E-mail address: add@iitmandi.ac.in (A. Dhar).

https://doi.org/10.1016/j.fuel.2018.02.108
Received 26 November 2017; Accepted 15 February 2018

Nomenclature

AMR	Adaptive mesh refinement
aTDC	After top dead centre, degrees
bTDC	Before top dead centre, degrees
CA	Crank angle, degrees
CA5	Crank angle at 5% mass fraction burn (SOC), degrees
CA50	Crank angle at 50% mass fraction burn, degrees
CA90	Crank angle at 90% mass fraction burn (EOC), degrees
CD	Combustion Duration, degrees crank angle
CDC	Conventional diesel combustion
CI	Compression ignition
CN	Cetane number
CO	Carbon monoxide, g/kWh
CR	Compression ratio
DDM	Droplet Discrete model
DI	Direct injection
EGR	Exhaust gas recirculation
EOC	End of Combustion, degrees
EVC	Exhaust valve close
EVO	Exhaust valve open
gIMEP	Gross indicated mean effective pressure, MPa
H_2	Hydrogen gas
HC	Hydrocarbon (unburnt), g/kWh
HCCI	Homogeneous charge compression ignition
HES	Hydrogen energy share,%
HRR	Heat release rate, J/CA
IVC	Intake valve close
IVO	Intake valve open
kJ	Kilo Joules
LTC	Low-temperature combustion
MPa	Mega Pascal
ms	Millisecond
NOx	Nitrogen Oxide, g/kWh
NTC	No time counter
O_2	Oxygen gas
PCCI	Premixed charge compression ignition
RCCI	Reactivity controlled compression ignition
RNG K-e	Re-Normalisation Group K-epsilon
RPR	Rate of pressure rise, MPa/CA
SOC	Start of combustion
SOI	Start of injection
TDC	Top dead centre
θ	Degree crank angle

hydrogen energy share increases. However, compression ratio decrease reduces the efficiency moderately. CO_2 addition for charge dilution and water injection along with hydrogen are also reported to increase the control over combustion process [14,15]. The combined effect of water injection and reduced compression ratio results in drastic reduction in cylinder peak temperature. Under such condition, hydrogen energy share is known to increase up to 79% at the compression ratio of 16.5:1. Also, resulting NOx emission is comparable to base diesel mode with drastically reduced HC, CO, and smoke emissions [16]. Such trends reported in the literature are suggestive that higher BTE and lowered Bsfc is achievable with hydrogen substitution if the engine operates at high compression ratios. However, increasing the compression ratio is sharply restricted by knocking tendency and material limits [17].

The literature points that CR has a strong influence on the possible percentage of HES in the case of dual fuel C.I. engines. However, limited studies are available, quantifying the relationship between CR and HES. Masood et al. reported that the peak in-cylinder pressure increase with HES at compression ratios ranging from 16.35 to 24.5 [18]. They found that combustion duration increase at low loads as the number of ignition centres reduces, which leads to drop in combustion rate. The present work aims to give insight into the effects of varying compression ratio and HES on C.I. direct injection diesel engine. The variation of CR in this work is kept between 14.5 to 19.5 in order to study the maximum possible knock free hydrogen substitution in automotive engines. Computational model created for prediction is validated using in-cylinder pressure data available in the literature. The effect of HES on ignition delay and combustion duration is also reported along with its effect on regulated emissions. Subsequent sections discuss in detail that hydrogen substitution reduces the ignition delay at high compression ratios. Furthermore, HES enhancement is found to increase HRR during the premixed phase and even results in pre-ignition before diesel injection at CR 19.5. Hydrogen was found effective in reducing HC, CO, CO_2 and soot emissions.

2. Model and validation

2.1. Computational model

CONVERGE CFD, a commercial I.C. engine simulation package is used as a computational framework for developing a model for hydrogen supplemented dual fuel C.I. engine. Hydrogen is port injected and considered to homogeneously distributed in the combustion chamber at the start of the simulation (at IVC). The liquid diesel injection process is simulated using standard DDM (Droplet Discrete model), and Hybrid KH-RT model is used to model atomization and break-up of spray along with NTC collision model [19–21]. RNG k-e is used to model turbulent flow along with wall function (O'Rourke and Amsden wall heat transfer model), which accounts for the heat transfer through the boundary [22]. Table 2 highlights the details of the engine used in this model.

CONVERGE CFD uses integrated chemistry solver code, named SAGE to model the combustion with detailed chemistry. N-Heptane is used as a fuel surrogate to model diesel during combustion due to its

Table 1
Important properties of diesel and hydrogen.

Properties	Diesel Properties	Hydrogen properties
Lower Heating Values (MJ/kg)	43	120
Stoichiometric air fuel ratio	14.5	34.2
Energy Density at 15°C and 100 kPa, MJ/m^3	35.8	10.3
Auto ignition temperature, K	530	858
Laminar burning velocity, m/s	0.3	2.65 -3.25
Flammability limits (% volume in air)	0.7 to 5	4 to 75
Density at 15°C and 100 kPa, MJ/m^3	848	0.0083
Diffusivity in air, cm^2/s	0.038	0.63

Table 2
Engine Specifications.

Description	Parameter Values
Engine type	CI Engine
Displacement Volume (CC)	947.3
Rated output (kW)	7.4
Rated Speed (rpm)	1500
Bore, Stroke (mm)	102, 116
Compression ratio	19.5:1
Connecting rod length (mm)	232.6
IVO and IVC (Degree crank angle)	43° before TDC and 67° after BDC
EVO and EVC (Degree crank angle)	87° before BDC and 39 ° after TDC
Liquid injector opening pressure (bar)	250 - 260
In-cylinder peak pressure (bar)	90