Applied Thermal Engineering 108 (2016) 764–773

Contents lists available at ScienceDirect

Applied Thermal Engineering

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

Research Paper

Effect of hydrogen and producer gas as secondary fuels on combustion parameters of a dual fuel diesel engine

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HIGHLIGHTS

- Maximum rate of pressure rise decreases with the increase of PG replacement than diesel.
- $PG:H_2 = 60:40$ shows lower maximum rate of pressure rise among other H_2 percentages.
- The peak pressure at 80% load for 30% and 50% H_2 replacement is lower than diesel.
- Heat release rate while using PG is less than diesel operation at all loads.

ARTICLE INFO

Article history:
Received 22 November 2015
Revised 21 July 2016
Accepted 23 July 2016
Available online 25 July 2016

Keywords:
Dual fuel diesel engine
Hydrogen
Producer gas
Rate of pressure rise
Peak pressure
Heat release rate

ABSTRACT

This study presents experimental investigation into the effects of using hydrogen, producer gas and mixture of producer gas and hydrogen in different proportion as a secondary fuel with diesel as pilot fuel in dual fuel operation. The combustion parameters studied are maximum rate of pressure rise, peak cylinder pressure and heat release rate in first phase of combustion at wide range of load conditions. Experiments were conducted on a 4 cylinder turbocharged and intercooled 62.5 kW gen-set diesel engine at constant speed of 1500 RPM. It was found that the maximum rate of pressure rise increases up to 30% of hydrogen substitution and decreases for onward substitution at all load conditions. Peak cylinder pressure also increases up to 30% of hydrogen substitution for 13% and 40% load conditions whereas, at 80% load it decreases with the increase of hydrogen fraction at all load conditions. When producer gas (PG) alone is used as secondary fuel, the maximum rate of pressure rise decreases over the entire range of its substitution while, the peak cylinder pressure increases initially up to 10% of producer gas substitution and for onward substitution of producer gas, it decreases at all load conditions. The heat release rate in first phase of combustion found to decrease during both types of fuel substitution as compared to diesel fuel. However, in mixed dual fuel mode, for all the different compositions tested, the composition $(PG:H_2 = 60:40)\%$ shows lower maximum rate of pressure rise and peak cylinder pressure. Further, at all load conditions decrease in heat release rate is observed and at 80% load condition it is found 47.29 J/°CA.

1. Introduction

Recently an experimental investigations on performance and emissions of a dual fuel diesel engine using hydrogen and producer gas (PG) (produced from rice husk) as secondary fuels were presented by the authors to examine the performances of dual fuel diesel engine [1]. Also, presents the mathematical modeling on performance and emissions of a dual fuel diesel engine using hydrogen [2] and producer gas [3] as secondary fuels. The developed models can be used to predict the important performance and emission parameters for diesel-hydrogen operation in various combinations at different loads within the experimental domain. However, thorough experimental results on some combustion parameters at various load conditions were not reported. Hence, this paper presents experimental results for different load conditions and gaseous fuel substitutions on the combustion parameters of a dual fuel turbocharged multi-cylinder diesel engine with hydrogen, producer gas and mixture of producer gas and hydrogen as secondary fuels. Important properties of the different fuels are shown in Table 1.

Roy et al. [4] observed rise in maximum cylinder pressure and the rate of heat release for the high hydrogen content producer gas for different equivalence ratios at various injection timings.

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http://dx.doi.org/10.1016/j.applthermaleng.2016.07.157
1359-4311/

Table 1
Properties of fuels.

Sr. No.	Properties	Diesel	Producer gas	Hydrogen
1	Lower heating value (kJ/kg)	42,800	6000	120,000
2	Minimum ignition energy (mJ)	–	–	0.26
3	Flame speed (cm/s)	2.0–8.0	20–30	265–325
4	Flammability limit (% volume in air)	0.6–7.5	7.0–21.6	4–75
5	Flammability limit (equivalence ratio)	0.6–2.0	–	0.1–7.1
6	Diffusion coefficient (cm^2/s)	–	–	0.61

Santoso et al. [5] investigated that peak cylinder pressure decreased for hydrogen enrichment of 5 and 10 N m respectively, whereas pressure rise was almost the same with that of diesel. However, rate of pressure rise and cylinder peak pressure reduced significantly for further increase in hydrogen flow rate. Lata et al. [6] observed increase in maximum rate of pressure rise and peak cylinder pressure as compared to pure diesel operation for use of hydrogen and LPG alone as secondary fuel. It was also found that the heat release rate in first phase combustion reduced at all load conditions as compared to pure diesel operation in both types of fuel substitution. Further, a significant rise in the performances of dual fuel diesel engine was noticed when mixture of LPG-hydrogen in different combinations used as secondary fuel.

Wang et al. [7] revealed that for specific ignition timing, the center of heat release rate moves close to the top dead center with the increase of hydrogen fraction which resulted from burning velocity enhancement by hydrogen addition. The combustion parameters such as maximum cylinder gas pressure, mean gas temperature, rate of pressure rise and heat release rate for different percentage of hydrogen blends had increasing trends with the advancing of ignition timings. Korakianitis et al. [8] found that dual-fuel operation with hydrogen generates higher peak combustion pressures compared with normal CI engine operation and it was occurred up to 4 °CA earlier. Further, the combustion was abnormal due to high pressure rise rates during diesel-hydrogen fuel operation. Saravanan et al. [9] observed rise in the peak pressure with the increase of hydrogen flow rate. At full load, it was 83 bar with hydrogen flow rate of 7.5 liters per minute and 85 bar with 9.5 liters per minute compared to 82 bar of diesel. Moreover, the heat release rate was higher compared to diesel. The maximum heat addition was occurred nearer to injection top dead center during hydrogen operation. Also, the combustion of hydrogen and diesel starts at the same crank angle of about 10 °CA before top dead center (BTDC).

Xu et al. [10] stated on performing experimentation over a single cylinder engine with natural gas-hydrogen mixture that under certain engine conditions the maximum cylinder gas pressure and heat release rate increased with the increase of hydrogen fraction. Lata et al. [11] developed theoretical models to predict cylinder pressure, net heat release rate and brake thermal efficiency for dual fuel engine using hydrogen and LPG separately and mixture of both as secondary fuels. This model predicted the engine combustion characteristics in closer approximation to that of experimental results. Szwaja et al. [12] used a dose of 5% and 15% hydrogen at constant diesel dose and showed increase in peak pressure as a result of the extra energy delivered to the combustion chamber. Moreover, the rate of in-cylinder pressure rise was lower during combustion particularly at an early stage with hydrogen addition of 5%.

Lilik et al. [13] observed that hydrogen caused the maximum in-cylinder pressure to increase in all modes of operation. The effect was greater in the high load modes, where more complete combustion of the fuel occurred. Also, hydrogen caused maximum peak pressure to occur earlier. Moreover, the heat released during mixed-controlled combustion phase was decreased with the increase of hydrogen substitution. Liew et al. [14] studied the effects of hydrogen addition on the combustion process of a heavy duty diesel engine. It was observed that, addition of a small amount of hydrogen had a negligible effect on the cylinder pressure and combustion process. However, when operated at high load the addition of a relatively large amount of hydrogen substantially increased the peak cylinder pressure and peak heat release rate.

Selim et al. [15] examined the effect of load on rate of pressure rise for the diesel and dual fuel engine at an engine speed of 1200 RPM and observed that the pressure rise rate for the dual fuel mode was always higher than that for the diesel fuel mode. Moreover, earlier injection of pilot fuel caused the maximum pressure to increase BTDC in the compression stroke. Banapurmath et al. [16,17] studied the effect of brake power on combustion parameters like peak cylinder pressure, maximum rate of pressure rise. It was observed that at 80% load, the peak pressure with Honge oil-PG was about 63.59 bar, for Honge oil methyl ester (HOME)-PG it was 67.6 bar and for diesel it was 71.52 bar respectively. The trends for the maximum rate of pressure rise were also similar. The premixed burning phase associated with a higher heat release rate was significant with diesel-PG dual fuel operation.

2. Experimentation

The experimental setup used in the present paper is same as in reference [1] and has been illustrated here in brief for the sake of clarity. A diesel engine test setup, model Ashok Leyland ALUWO4CT, turbocharged with inter-cooler and gen-set was developed to carry experimental investigation. The detailed specification and operating parameters for the present work is given in Table 2. A schematic layout of the diesel engine test setup used during the experiments is shown in Fig. 1 [1].

Table 2
Engine specification.

Sr. No.	Parameter	Engine specification
1	Make and model	Ashok Leyland ALU WO4CT Turbocharged, inter-cooler, Gen-Set
2	General details	Four Stroke, Compression Ignition, Constant Speed, vertical, water-cooled, direct injection, turbo charger, Intercooler, Gen-Set
3	No. of cylinder	4
4	Bore (mm)	104
5	Stroke (mm)	113
6	Rated speed (rpm)	1500
7	Swept volume (cc)	3839.67
8	Clearance volume (cc)	84.90
9	Compression ratio	17.5:1
10	Injection pressure bar	260
11	Injection timing BTDC	16°
12	Rated power (kW) at 1500 rpm	62.5
13	Inlet pressure bar	1.06
14	Inlet temperature (K)	313
15	Nozzle diameter (mm)	0.285
16	Number of hole	5