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Effect on performance and emissions of a dual fuel diesel engine using hydrogen and producer gas as secondary fuels

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ARTICLE INFO

Article history:
Received 10 December 2013
Received in revised form
28 February 2014
Accepted 8 March 2014
Available online 13 April 2014

Keywords:
Dual fuel engine
Combustion
Modeling
Alternative fuels
Hydrogen
Producer gas

ABSTRACT

Energy is an essential prerequisite for economical and social growth of any country. Sky-rocketing of petroleum fuel cost s in present day has led to growing interest in alternative fuels like CNG, LPG, Producer gas, Biogas in order to provide suitable substitute to diesel for a compression ignition engine. This paper discusses some experimental investigations on dual fuel operation of a 4 cylinder (turbocharged and intercooled) 62.5 kW gen-set diesel engine with hydrogen, producer gas (PG) and mixture of producer gas and hydrogen as secondary fuels. Results on brake thermal efficiency and emissions, namely, un-burnt hydrocarbon (HC), carbon monoxide (CO), and NO_x are presented here. The paper also contains vital information relating to the performances of an engine at a wide range of load conditions with different gaseous fuel substitutions. When only hydrogen is used as secondary fuel, maximum increase in the brake thermal efficiency is 7% which is obtained with 20% of secondary fuel. When only producer gas is used as secondary fuel, maximum decrease in the brake thermal efficiency of 8% is obtained with 30% of secondary fuel. Compared to the neat diesel operation, proportion of un-burnt HC and CO increases, while, emission of NO_x reduces in all Cases. On the other hand, when 40% of mixture of producer gas and hydrogen is used (in the ratio (60:40) as secondary fuel, brake thermal efficiency reduces marginally by 3%. Further, shortcoming of low efficiency at lower load condition in a dual fuel operation is removed when a mixture of hydrogen and producer gas is used as the secondary fuel at higher than 13% load condition. Based on the performance studied, a mixture of producer gas and hydrogen in the proportion of 60:40 may be used as a supplementary fuel for diesel conservation.

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http://dx.doi.org/10.1016/j.ijhydene.2014.03.085

Introduction

Concern over current crude oil supplies in addition to varying oil prices has resulted in the wide evaluation of substitution of alternative sources of fuel. With the increasing need to conserve fossil fuel and minimize toxic emissions much effort is being focused on the advancement of present combustion technology. This has inspired to explore and testing of several alternative fuels such as alcohol, gas viz. CNG, LPG, biogas, producer gas, and hydrogen, which have been studied extensively [1]. Among these alternative fuels, hydrogen shows great potential. Important properties of hydrogen are given in Table 1.The advantage of using hydrogen as fuel for internal combustion engine in dual fuel mode is less polluting, non-toxic, odorless, and has wide range of flammability amongst other fuels [2,3]. Similarly, in comparison to other alternative sources of energy particularly in rural areas, producer gas from biomass appears to have the greatest potential. As an agricultural country, India has large variety of biomass feedstock available in huge quantity. As these are available locally, biomass gasifier-based power generation may be an appropriate option for decentralized power generation in many parts of the country [4]. It is estimated that about 40%–60% of agricultural residues are either lost or put in to inefficient use. In the current context of scarcity of petroleum fuels, this recognizes for better utilization of these resources by thermo-chemically converting into producer gas [5]. The producer gas and hydrogen are seems to be two potential alternative fuels. Hydrogen dual fuel engines have many attractive features, but they tend to suffer from premature ignition called knocking, particularly under high load conditions because of hydrogen's lower ignition energy, wider flammability range and shorter quenching distance [3]. This problem is less severe while using producer gas as fuel in dual fuel mode although producer gas contains 12–20% hydrogen [3].

Many researchers have carried out works on either hydrogen [1–3,8–14] or producer gas only [4–7,15–20] as a secondary fuel in diesel engines. Lata et al. [1] observed appreciable and eco-friendly performance of an engine using mixture of hydrogen and LPG while experimenting with hydrogen, LPG, and a mixture of LPG-hydrogen in various proportions in different combinations as secondary fuels and diesel as a pilot fuel. Santoso et al. [2] identified the benefit of decreased in diesel fuel consumption with slight increased in brake thermal efficiency with the H_2 enrichment at 15 Nm load and at lower load the efficiency decreases.

Saravanan et al. [9] found increased in brake thermal efficiency and reduction in NO_x with H_2 as an enrichment medium and diesel as an ignition source. The effect of H_2 addition into the intake air on NO_2 emission at 1200 RPM was examined by Liu et al. [10] and observed that, an addition of small amount of H_2 increase substantially the emission of NO_2 and NO_2/NO_x ratio particularly at low load. Maximum NO_2 of the H_2-diesel dual fuel operation was three to five times more than that of diesel operation at 70% and 10% load conditions, respectively. Gomes Antunes et al. [11] achieved higher fuel efficiency in hydrogen-fueled engine by approximately 43% as compared to 28% in the conventional diesel engine along with 20% reduction in NO_x formation than diesel engine due to direct injection of hydrogen in diesel engine. Boretti et al. [12] observed higher brake thermal efficiency nearer to 40% as compared to original diesel engine by introducing modified double injector one for hydrogen and other for diesel in common rail diesel engine.

Das et al. [5] investigated slight drop in average value of thermal efficiency from 32.35% on diesel to 28.7% dual fuel mode using pigeon pea stalks as biomass fuel. However, thermal efficiency found on dual fuel mode with wood chips and corn cabs is comparable to diesel. Banapurmath et al. [15,16] injected diesel, honge oil, rice bran, neem oil with producer gas in dual fuel mode which resulted in lower brake thermal efficiency than single fuel operation. No_x emission was found to be lower whereas HC, CO was found to be more than single fuel operation.

Ramadhas et al. [17,18] analyzed decrease in engine performance with rise in HC and CO emissions from the dual fuel mode than that when rubber seed oil/diesel alone was used under all load conditions. The study proved that the existing diesel engine was capable of successful running in dual fuel mode of operation using coir-pith and wood chips derived producer gas. However, higher the capacity of engine than the required capacity was to be selected because the producer gas dual fuel engine could run only at maximum of 50–60% of maximum load. Singh et al. [7] investigated increase in exhaust gas temperature and SEC in all modes of operation compared to diesel using diesel and refined rice bran oil in different proportion and producer gas from a wood gasifier in dual fuel mode and mixed fuel mode at different loads. However, brake thermal efficiency decreased and concentration of pollutants like NO_x reduced by 82% respectively, while HC and CO increased as compared to diesel.

Roy et al. [4] analyzed the effect of hydrogen content in producer gas on the performance and exhaust emissions of a supercharged producer gas-diesel dual engine. The engine power with the high H_2 content producer gas was 12% higher at the lower end of the optimum fuel-air equivalence ratio $\phi = 0.42$ and was 2% higher at the upper end of the optimum $\phi = 0.79$ than that with the low H_2 content producer gas. Sridhar et al. [19] revealed that it is possible to operate commercially available natural gas engines on low energy density producer gas by employing suitably designed carburetor. Even though it causes loss of power to an extent of

Table 1 – Important properties of hydrogen.

Sr. no.	Properties	Diesel	Producer gas	Hydrogen
1.	Lower heating value (kJ/kg)	42,800	6000	1,20,000
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