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An experimental study on combustion, performance and emission analysis of a single cylinder, 4-stroke DI-diesel engine using hydrogen in dual fuel mode of operation

Madhujit Deb, G.R.K. Sastry, P.K. Bose, Rahul Banerjee*

Mechanical Engineering Department, NIT Agartala, Tripura 799046, India

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ABSTRACT

The hydrogen-diesel dual fuel combustion was investigated in direct injection (DI) diesel engine. The investigation presented in this paper preferred hydrogen as a long-term renewable and least polluting fuel among various alternative fuels for internal combustion (IC) engines. In the current study a diesel engine is made to run using hydrogen in dual fuel mode with diesel, where hydrogen is introduced into the intake manifold using an LPG-CNG injector and pilot diesel is injected using diesel injectors. The hydrogen energy contents of the total fuel were varied from 0%, 11%, 17%, 30% and 42% (the 0% hydrogen energy content represents neat diesel fuel), were experienced at (1500 ± 10) rpm of invariable engine speed and 5.2 kW of consistent indicated power. The test results showed the improvement in brake thermal efficiency (BTHE) of the engine, reduction in brake specific energy consumption (BSEC) with an increasing hydrogen energy fraction. Furthermore, indicated specific CO, CO_2 and smoke emissions decrease with an increasing percentage of hydrogen energy content. Conversely, indicated specific NOx emissions increases with increase in hydrogen content. In addition to that, it was also observed that there was a sharp increase in peak in-cylinder pressure and the peak heat release rate values with the increasing hydrogen rate.

Introduction

To facilitate the enhancement in the performance of diesel engines the addition of hydrogen to conventional diesel fuel in the compression ignition (CI) engine have been proposed by many researchers because it raises the H/C ratio of the entire fuel and reduces the combustion duration due to high speed of flame propagation of hydrogen in relation to other fuels [1–11]. Besides, injecting a small amount of hydrogen to a diesel engine decreases the heterogeneity of diesel fuel spray due to high diffusivity of hydrogen which crafts the combustible mixture better premixed with air and results in more homogeneous mixture [16]. The major drawbacks with

* *Corresponding author*. Mechanical Engineering Department, National Institute of Technology, Agartala, Barjala, Jirania, Tripura 799046, India. Tel.: +91 9436582714; fax: +91 381 2346630.
E-mail address: madhujit_deb@rediffmail.com (M. Deb).
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hydrogen as a fuel are combustion knock, high in-cylinder peak pressures and temperatures, results in higher amounts of (NOx) emissions and high self-ignition temperature [4,8–11]. A number of investigations have been reported on pure hydrogen combustion in (CI) engines and also on the combustion of hydrogen-diesel dual fuel strategies. Saravanan et al. [3] worked with hydrogen enrichment to the diesel fuel. Hydrogen was altered in the range from 10% to 90% by volume. Initially the engine was started with diesel fuel; later the diesel flow rate was reduced and hydrogen was supplied to the intake manifold. Diesel flow was reduced up to 10% of the baseline value and hydrogen flow was increased until the engine attained the rated speed of 1500 rpm. They concentrated on emission and performance characteristics of the engine at various hydrogen doses and concluded that knock can occur if only the hydrogen enrichment equals 50% or more at full load of the engine. Furthermore they found reduction in hydro carbons (HC) and (NOx) emissions. Based on their study they concluded that the optimal hydrogen enrichment with diesel was 30%. Senthil et al. [12] studied the application of hydrogen to improve combustion of vegetable oil in a diesel engine. In their study, experiments were carried out to evaluate the engine performance while using small quantities of hydrogen in a compression ignition engine primarily fueled with a vegetable oil, specifically Jatropha oil. An increase in the brake thermal efficiency was observed from 27.3% to a maximum of 29.3% at 7% of hydrogen mass share at the maximum power output. They also observed the considerable reduction in smoke by 20% with a reduction in (HC) and (CO) emissions from 130 to 100 ppm and 0.26%–0.17% (by volume), respectively. The optimal hydrogen mass share was found to be 7%. By means of hydrogen induction, the (NO) level was increased from 735 to 875 ppm at full output due to its elevated combustion rate. It was also observed that ignition delay, peak in-cylinder pressure and the maximum rate of pressure rise were amplified in the dual fuel mode of operation with hydrogen. Reduction in combustion duration was observed due to higher flame speed of hydrogen. Additionally, a higher premixed combustion rate was observed with hydrogen induction. Antunes et al. [13] in their study employed hydrogen directly in a single-cylinder, air-cooled, normally aspirated, direct injection diesel engine by heating the intake air to 80 °C with a specifically designed high pressured H_2 injector. Consequently, an increase in 14% of power with an increase in thermal efficiency from 28% to 43% was observed. Besides, a decrease of 20% on NOx emission formation was also obtained. It is possible to use hydrogen in a dual fuel mode in a CI engine. In this mode, ignition can be apprehended by diesel pulverization because hydrogen is the main fuel, and it is recognized as the most sensible method when combustion permanence is considered. Thus, timing manifold/port injection, direct hydrogen injection and continuous manifold injection methods are applied [14]. In case of continuous manifold injection method, as a result of abnormal combustion, such as knock, pre-ignition and backfire, the engine operational area is restricted. During time manifold/port injection and continuous manifold direct injection methods, a part of intake air is replaced by hydrogen due to drop of volumetric efficiency, a decrease in engine power is observed [14]. These difficulties can be managed by direct hydrogen injection. On the other hand to implement direct hydrogen injection method a modification of the diesel engine and the involvement of a high pressure H_2 injector on the cylinder head is essential. Hydrogen has a wider flammability limit, higher flame speed and faster combustion velocity [15–17] in comparison to diesel fuel. Furthermore, hydrogen has a short quenching distance, elevated thermal value and high diffusivity [11]. Thus, the use of hydrogen in diesel engines in dual fuel mode by diesel pulverization is beneficial because PM emissions are reduced [18]. Since hydrogen does not contain carbon, CO_2, HC and CO emissions are also reduced. Bose and Maji [19] performed their experimental investigations on a 4-stroke, water-cooled, single cylinder diesel engine and where a quantity of 0.15 kg/h of hydrogen was introduced from the intake manifold via a solenoid valve. The testing were performed at 20%, 40%, 60% and 80% full load condition along with 10% and 20% EGR (exhaust gas recirculation) conditions. The results obtained were then compared to the pure diesel and the diesel-hydrogen dual fuel modes. An enhancement in the thermal efficiency with a reduction of CO, CO_2, THC and soot emissions were observed with the use of hydrogen. The NOx emissions were restricted with EGR treatment. Liew et al. [19] studied the upshot of hydrogen on the combustion process with varying the engine load and hydrogen quantity in a 4-stroke, 6-cylinder, heavy-duty diesel engines. It was observed that at 70% load with a increased hydrogen quantity, the combustion duration reduced and the peak heat release rate amplified. Kose and Ciniviz [14] studied the effects on engine performance and exhaust emissions at 2.5%, 5% and 7.5% hydrogen volumes as a accompanying fuel at full load for several engine cycles in a 4-stroke, water-cooled, 4 cylinder, direct injection diesel engine. It was observed that with hydrogen addition the NOx emissions and the exhaust temperature increase moreover the HC, CO and O_2 emissions were decreased. A four-cylinder, direct injection, naturally aspirated diesel engine was used for investigation by Morais et al. [21] where the engine load was varied between 0 kW and 40 kW with 0%, 5%, 10%, 15%, 20% of hydrogen energy share. The results showed the decrease in CO_2 emissions up to 12% with increasing hydrogen flow rate as compared with neat diesel fuel in conjunction with insignificant decrease in bsfc and effective engine efficiency. Christodoulou and Megaritis [21] performed their experimentation on a Ford Puma, 4-cylinder diesel engine where hydrogen or nitrogen with 2% up to 8% of total intake charge on volume basis was inducted into engine. They concluded that with hydrogen addition NOx emissions were increased while smoke and CO emissions were decreased compared with neat diesel fuel. On the other end NOx emissions were decreased while smoke, CO and bsfc values were increased, with nitrogen addition compared with neat diesel fuel. Saravanan et al. [22] performed their experimental investigation with introducing a constant supply of hydrogen of 10 slpm at 23^0BTDC (before top dead centre) injection advance for diesel to a single-cylinder, water-cooled, vertical, naturally aspirated, stationary, DI (direct injection), diesel engine. Three different hydrogen injection times were chosen (30^0CA, 60^0CA and 90^0CA) with 5 different hydrogen injection advances (-5^0BTDC, TDC, 5^0ATDC,10^0ATDC, and 15^0ATDC) for investigation. It was observed that for a H_2 injection at5^0ATDC (after