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The effect of hydrogen on the performance and emissions of an SI engine having a high compression ratio fuelled by compressed natural gas

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ABSTRACT

The aim of this paper is investigation of the effect of hydrogen on engine performance and emissions characteristics of an SI engine, having a high compression ratio, fuelled by HCNG (hydrogen enriched compressed natural gas) blend. The experiments were carried out at 1500, 2000 and 2500 rpm under full load conditions of a modified Isuzu 3.9 L engine, having a compression ratio of 12.5. The engine brake power, brake thermal efficiency, combustion analysis and emissions parameters were realized at 5, 10 15 and 20 deg. CA BTDC (crank angle before top dead center) ignition timings and in excess air ratios of 0.9 −1.3 fuelled by hydrogen enriched compressed natural gas (100/0, 95/5, 90/10 and 80/20 of % natural gas/hydrogen).

The experimental results showed that the maximum power values were generally obtained with HCNG5 (5% hydrogen in natural gas) fuel. The optimum ignition timing that was obtained according to the maximum brake torque was retarded by the addition of hydrogen to CNG (compressed natural gas), while it was advanced by increasing the engine speed. Furthermore, it was observed that the BTE (brake thermal efficiency) generally declined with the hydrogen addition to compressed natural gas and increasing the engine speed. Additionally, the curves of cylinder pressure and ROHR (rate of heat release values) generally closed to top dead center with the increasing of the hydrogen fraction in the blend and a decreasing engine speed. The hydrocarbon and carbon monoxide emissions generally obtained were lower than the Euro-5 and Euro-6 standards.

Introduction

Due to rising oil prices and increased air pollution, many researchers have studied the viability of HCNG as an alternative fuel to improve engine performance and emissions values. These studies were performed using different percentages of hydrogen, ignition timings and compression ratios or with modified geometries. For instance, in the experiment by Xu et al. [1] the effect of hydrogen addition on the engine

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performance and emissions of an SI engine, fuelled by CNG, showed that a relatively higher thermal efficiency can be achieved under certain fixed engine conditions when adding more than 20% of hydrogen by volume to CNG. In a similar study, Kahraman et al. [2] showed that the highest brake thermal efficiency was obtained at 30% H_2 to natural gas. In addition, some tests carried out by Mohammed et al. [3], Taggart-Cowan et al. [4] and Akansu et al. [5] indicated that adding H_2 to CNG raised thermal efficiency and reduced emissions.

Furthermore, many researchers have investigated engine performance and emission parameters using different ignition timing. For example, Huang et al. [6] analyzed combustion characteristic in a SI engine fuelled by HCNG blends of (0/100, 5/95, 10/90 and 18/82 of % H_2/NG) under lean mixture conditions using different ignition timings (20–44 deg. CA BTDC). They found that the brake mean effective pressure and effective thermal efficiency increased while HC decreased and the NO_X increased while advancing the ignition timings. In another study, Deng et al. [7] highlighted that the indicated thermal efficiency could be increased by advancing the ignition timing, until reaching the maximum value which is about 20–25 deg. CA BTDC and emission values can be reduced by retarding the ignition timing for the hydrogen fractions of 0%, 30%, 55% and 75% by volume. Moreover, Lim et al. [8] analyzed the effects of ignition timing retard strategy on NOx reduction in hydrogen-compressed natural gas blend engines with an increased compression ratio. They showed that thermal efficiency could be improved and NO_X emission significantly reduced with an increasing CR. In another study, Poompipatpong and Cheenkachorn [9] analyzed engine performances and emissions with 9, 9.5, 10 and 10.5 CR for CNG fuels in an SI engine. The study indicated that the highest thermal efficiency and the lowest specific fuel consumption were obtained at 9.5 CR while the highest torque was obtained at CR of 10:1 at low speed. HC (hydrocarbon) emissions were directly proportional to the CR. NO_X emissions increased with increasing CR and then declined when 10 CR.

Since the present study could be a reference for commercial engines, it would be appropriate to analyzing of the studies about the vehicles driven on road. In one of these studies [10] carried out by running fixed tracks, which were representative of urban and suburban driving cycles. Vehicles were powered with a lean burn engine whose setup - based on ignition advance angle. Two buses for urban transit service were fuelled with HCNG blends with different percentage of hydrogen (5%, 10%, 15%, 20% and 25% of hydrogen by volume) in the tests. The results of tests indicated that HC and CO were decreased with the increase of H_2 percentages although a fine tuning in both ignition advance timing and leaning air fuel ratio was necessary to decrease the NOx emissions. In the other studies [11] carried out on vehicles, the researchers aimed the identifying the prospective of the use of blends of natural gas and hydrogen in existing internal combustion engines vehicles. The tested vehicle was an IVECO Daily CNG, originally fueled with natural gas and the tests had been made on the a driving cycle comparing the emission levels of the original configuration (CNG) with the results obtained with different blends (percentage of hydrogen in the fuel) and control strategies (stoichiometric or lean burn). The study shown that the emissions levels were even lower than the original CNG ones, ones, especially for NOx, using the optimized maps for the stoichiometric conditions. Moreover, the HCNG10 the vehicle presented the lowest emission levels. For lean burn mixtures, the emissions presented two different behaviors: the CO emissions were always lower for blends with 10% and 15% of H_2 by volume. Nevertheless, concerning the NOx emissions, the values were lower than those ones using pure CNG, but not as good as stoichiometric values. Furthermore, HC emissions increased for the lower combustion quality due to lean mixture.

Recently, many researchers have studied the opportunity of improving engine performance and emissions using HCNG fuels as an alternative fuel. Nonetheless, most of these studies were implemented in an SI engines having a low compression ratio. As can be seen from Refs. [3,9,12–14], only a few studies have applied at high compression ratios. For this reason, in the present study, the authors aimed to analyze engine performance and emissions in an SI engines having a high compression ratio using HCNG fuels.

Experimental setup and test procedure

The experiments were conducted in a modified Isuzu 4BD1 3.9 L engine. Table 1 shows the specifications of the experimental engine. The engine has been preferred due to its widespread use in light commercial vehicles and providing an important commercial market opportunity for HCNG alternative fuel. It is also the reason why it is preferable that the engine can be easily converted to a natural gas engine. Fig. 1 shows the experimental set-up. Moreover, torque and speed values of the engine were measured using A Cussons P8601 hydraulic dynamometer. In the experiments, the fuels (H_2 and CNG) were stored in 2 pressurized tanks at 200 bar. The pressures of both H_2 gas fuel and CNG fuel were reduced from 200 bar to 12 bar using a regulator. The volumetric blending of H_2 and CNG fuels was made in a Witt MM-Flex mixer unit. Then, the gas pressures of the blend fuels were reduced from 12 bar to 1 bar using pressure regulators. For the gas flow measurements, an Alicat 1000 SLPM type flow meter was used. Finally, HCNG blends were injected into the intake manifold.

Ignition timing and fuel flow were controlled using Megasquirt II engine control unit and its software program without any engine tuning. The cylinder pressure values were measured with a PCB 112A05 pressure transducer, Cussons

Table 1 – Features of the experimental engine.

Engine	Isuzu 4BD1
Cylinders	4 in line
Engine stroke volume (L)	3.856
Bore/stroke (mm)	102/118
Compression ratio	17.5
Modified compression ratios	12.5
Modified engine volume (L)	4.16
Max. power (kW)	70 (3200 rpm)
Max. torque (N.m)	245 (1900 rpm)
Idle/max. speed	650/3500 rpm
Min. SFC (g/kw.h)	216

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