INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 40 (2015) 8750–8760

Available online at www.sciencedirect.com

ScienceDirect

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

Effect of hydrogen and oxygen addition as a mixture on emissions and performance characteristics of a gasoline engine

Y. Karagöz [a,**], N. Yuca [b], T. Sandalcı [a], A.S. Dalkılıç [c,*]

[a] Automotive Division, Department of Mechanical Engineering, Mechanical Engineering Faculty, Yildiz Technical University, Yildiz, Besiktas, Istanbul 34349, Turkey

[b] Institute of Energy, Istanbul Technical University, Istanbul 34469, Turkey

[c] Heat and Thermodynamics Division, Department of Mechanical Engineering, Mechanical Engineering Faculty, Yildiz Technical University, Yildiz, Besiktas, Istanbul 34349, Turkey

ARTICLE INFO

Article history:
Received 10 February 2015
Received in revised form
3 May 2015
Accepted 6 May 2015
Available online 29 May 2015

Keywords:
SI engine
Additional fuel
Electrolysis
Emission
Combustion

ABSTRACT

Use of hydrogen in spark ignition engines as supplementary fuel can be preferred due to improved combustion characteristics and emission advantages. However, hydrogen storage and production difficulties under the hood limit the use of it in internal combustion engines (ICEs). In this study, a different approach was used to overcome these difficulties. Hydrogen and oxygen gas mixture was produced by electrolyser and consumed simultaneously to eliminate the necessity of a storage device. Firstly, a practical alkaline water electrolyser was designed and manufactured to produce hydrogen from water to be subsequently used in ICE as a supplementary fuel. In order to optimize electrolyser, the parameters of gap between plates, concentration of solution and voltage were kept under control. Then, H_2/O_2 gas mixture used as secondary fuel in SI engine was generated by electrolyser on optimized operating conditions. 0 and 20 l/min H_2/O_2 mixture as supplementary fuel was introduced into intake manifold of engine using gas injectors where 0 l/min refers to without hydrogen case and 20 l/min with hydrogen case. According to the results, the brake power and brake thermal efficiency were increased by means of hydrogen addition. Besides, total hydrocarbon and carbon monoxide emissions decreased, whereas the dramatic increase of nitrogen oxides emissions couldn't be prevented during the experimental work.

* *Corresponding author*. Tel.: +90 212 383 2821; fax: +90 212 383 2765.
** *Corresponding author*. Tel: +90 212 383 2901; fax: +90 212 383 2765.
E-mail addresses: ykaragoz@yildiz.edu.tr (Y. Karagöz), dalkilic@yildiz.edu.tr (A.S. Dalkılıç).

http://dx.doi.org/10.1016/j.ijhydene.2015.05.039
0360-3199/

Introduction

Although the current energy and environment policies has forced researchers to be interested in non-polluting and clean alternative fuels for transport sectors, most of the energy demand is still supplied by fossil fuels. Even though the measures taken by Kyoto Protocol to the United Nations Framework Convention on Climate Change, during the period of 1990–2004, CO_2 emission increased by 27%, and the energy consumption in transport sector increased by 37% [1,2]. In relation with previous studies, hydrogen has been proved to be a green alternative energy and would be used on vehicles [3]. Fossil fuel can be substituted in part, by an alternative energy source, such as hydrogen [4]. Automotive manufacturers have profited from different technologies such as fuel cell, hydrogen fuelled ICE and hybrid configurations to evolve different type of vehicles. Some manufacturers study on polymer electrolyte membrane fuel cell (PEMFC). Since investment costs of PEMFCs are high and produced devices work only with high purity hydrogen (above 99.99%), fuel cell system becomes even more expensive [1].

Hydrogen's unique combustion properties may improve thermal efficiency and emission levels in ICEs, and may be useful for fuel saving. The diffusion coefficient of hydrogen (0.61 cm^2/s) is larger than gasoline (0.16 cm^2/s), for that reason, it improves the homogeneity of combustible mixture [5]. The aidabatic flame speed of hydrogen (237 cm/s) is five times as large as that of gasoline (42 cm/s) and therefore it may improve thermal efficiency, because the combustion of hydrogen engines is much closer to ideal constant volume combustion [5,6]. One of the possible ways to increase performance of an engine is to use additive as a supplementary fuel, leading to improve thermal efficiency and reduce emissions [7]. Some researchers have investigated different additives such as Jathropha Oil, 2-methoxyethyl acetate etc in diesel and gasoline engines [8]. However, hydrogen is the most promising additive with its unique combustion properties among many additives and it can reduce fuel consumption and harmful emissions emitted by ICEs [7] significantly. Karagoz et al. [9] used H_2/O_2 mixture as a supplementary fuel in an SI engine at idle condition, and it was found that brake thermal efficiency of engine increased, HC and CO_2 emissions decreased via hydrogen addition. H_2/O_2 mixture was used as supplementary fuel in a diesel engine at 1500 rpm constant engine speed and at different loads by Bari et al. [7]. Brake thermal efficiency of engine increased with H_2/O_2 addition. HC, CO_2 and CO emissions decreased, while the NO_x emissions increased. 3% and 6% hydrogen volume fraction of total intake was used as secondary fuel at 1400 rpm constant engine speed by Ji et al. [5]. Brake thermal efficiency of engine increased with hydrogen addition. Conversely, HC and CO emissions reduced with hydrogen addition. Hydrogen was introduced into biodiesel and diesel by Senthil et al. [10] during their experiment. Brake thermal efficiency of the engine with hydrogen enriched fuels was observed to be higher than the engines with conventional fossil fuels. Emissions also decreased. Tomita et al. [11] introduced hydrogen as secondary fuel into diesel fuel and observed a reduction in exhaust emission. 10 l/min and 20 l/min hydrogen were introduced into cylinders in experiment of Saravan et al. [12,13] and then performance parameters with/without EGR were prospected, and an increase in brake thermal efficiency was observed. Andrea et al. [14] studied on the effect of various engine speeds and equivalance ratios on combustion of a hydrogen blended gasoline engine. Combustion duration reduced with increase on hydrogen blending fraction. Mechanism of the toxic emission formation process for an engine fuelled with hydrogen-gasoline mixture was studied by Li et al. [15]. NO_x, HC and CO emissions released from the hydrogen-enriched gasoline engine were lower than the original one. Effect of hydrogen addition on a gasoline-fueled engine performance was studied by Ji and Wang [16] at idle and stoichiometric conditions. It was seen that the engine thermal efficiency and emissions accelerated after hydrogen enrichment. Wang et al. [17] experimented on effect of 3% hydroxygen (H_2+O_2) addition on engine performance in 1.6 L gasoline engine at 61.5 kPa manifold absolute pressures. Thermal efficiency increased with hydrogen proportion raise in hydroxygen gas mixture, moreover HC, CO, NO_x emissions recuperated. Ceviz et al. [18] studied on hydrogen addition of 0%, 2.14%, 5.28%, and 7.74% by volume to a spark ignition engine at 2000 rpm constant engine speed. Ji et al. [19] studied on emissions of a passenger car powered by a hydrogen-gasoline engine under the New European Driving Cycle. Ji et al. [20] observed via CFD calculation effect of 3% and 6% hydrogen addition by volume into gasoline. According to obtained results, peak flame propagation increased by 37.18% and 60.47% with 3% and 6% H_2 addition. Greenwood et al. [21] studied with H_2 and ethanol fuel mixture in a 0.745 L, two cylinder spark ignited engine. At ultra lean operating conditions, NO_x emissions decreased by 95% compared to stoichiometric gasoline operating conditions at stable engine speed with 0%, 15% and 30% H_2 addition by volume. Lee et al. [22] studied on a naturally aspirated gasoline engine with H_2 and low calorific gas blends at EGR and lean burn mode. Low calorific gas blends are composed of 40% natural gas, 60% nitrogen gas mixture and it corresponds to 0%–20% of H_2 gas mixture by volume. Although a decrease exists on brake thermal efficiency and an increase on THC emission at all H_2 added gas mixtures with EGR working condition, there is a decrease on NO_x emissions compared to lean burn working condition.

Most of the investigations focused on usage of pure hydrogen as secondary fuel but this may cause storage problems. Hydrogen has very low density, so it can be stored by compression in tanks (typically 70 MPa) or can be combined chemically with a metal alloy [7]. However, a tank with sufficient amount of hydrogen which increases overall system weight is needed for storage of hydrogen on-board [23]. Alternatively, liquid hydrogen storage method is used, but on-board cryogenic container costs are high and a high level of energy is needed to convert gaseous hydrogen into liquid [24]. In order to eliminate hydrogen storage problem, hydrogen could be produced on-board through the electrolysis of water. In this way, there will be no need for a high pressure tank. In the on-board hydrogen production systems, hydrogen is only produced while the engine is being operated and the produced gas has just been sent into the intake manifold.

Water electrolysis technology is easily classified into three approaches, with each approach conducting one of three ionic