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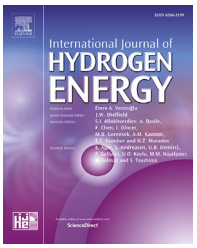

Effect of hydrogen addition using on-board alkaline electrolyser on SI engine emissions and combustion

Yasin Karagöz [a,*], Özgün Balcı [a], Emre Orak [a], Mostafa S. Habib [b]

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

[b] Department of Mechanical Engineering, Mechanical Engineering Faculty, University of Bahrain, Sakheer, 32038, Bahrain

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ABSTRACT

In this study, an electrolyser was used to supply hydrogen to the SI engine. Firstly, the appropriate operation point for the electrolyser was determined by adjusting the amount of KOH in the electrolyte to 5%, 10%, 20% and 30% by mass, and applying 12 V, 16 V, 20 V, 24 V and 28 V voltages. Tests were first carried out with the gasoline without the use of an electrolyser, followed by operating the electrolyser at the appropriate point and sending obtained H_2 and O_2 to the engine in addition to the gasoline. The SI engine was operated between 2500 rpm and 3500 rpm engine speeds with and without hydrogen addition. Cylinder pressure, the amount of gasoline, H_2 and O_2 consumed by the engine and the emission data were collected from the test system at the aforementioned engine speeds. Furthermore, indicated engine torque, indicated specific energy consumption, specific emissions and HRR values were calculated. According to the results obtained, improvement in ISEC values was observed, and CO and THC values were improved by up to 21.3% and 86.1% respectively. Even though the dramatic increase in NO_x emissions cannot be averted, they can be controlled by equipment such as EGR three-way catalytic converter.

Introduction

Today, both the total number of vehicles in the passenger and commercial vehicle markets and the increase in diesel vehicles in the market [1] cause the biggest negative effects on health by increasing NO_x and PM emissions [2]. Especially in Europe it is planned to limit the use of diesel vehicles apart from the commercial diesel vehicles in the city centers [3,4]. On the other hand, increased emission regulations and Euro standards have directed researchers to study on alternative fuel and energy types.

The fact that diesel engines work with cheaper fuel and are more efficient is a reason that makes them used on a large scale, however, high smoke and NO_x rates have lately caused a reduction of use of diesel engine powered vehicles. In addition, the ever-increasing emission standards make it necessary to improve the emission characteristics of gasoline engines and cause researchers to focus in this area. Hydrogen addition in spark-ignition internal combustion engines (ICEs)

* *Corresponding author.*
E-mail addresses: ykaragoz@yildiz.edu.tr (Y. Karagöz), mhabib@uob.edu.bh (M.S. Habib).

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can be used to improve combustion characteristics to meet today's increasing emissions standards. For this reasons, researchers try to develop technologies about SI engines. However, the low energy density and easy flammability of the unit volume of hydrogen make it harder to store and safely protect. In order to avoid these disadvantages and to reduce the cost, hydrogen additives can be provided simultaneously on-board with the aid of an electrolyser during the engine operation.

As a solution to the problems mentioned above, studies are being carried out for electric engine vehicles. But this technology is limited by the inadequacy of the development of battery technology and battery charging stations [5]. Similarly, Proton Exchange Membrane Fuel Cell (PEMFC) technology is limited by the difficulties on hydrogen purification and storage and the high cost it results, hence few models of FC vehicles are currently commercially available [5]. At the same time, engine start-stop technology, which reduces fuel consumption under idling conditions, provides an advantage in urban heavy traffic especially in large cities with a large number of vehicles. In addition, the method of adding hydrogen to the fuel provides a reduction in exhaust emissions under both partial loads and idle conditions. In this respect, it is considered that the hydrogen addition, which is easier to obtain than the fossil fuels and provides a cleaner combustion characteristic, will serve as a bridge in the transition process of the Fuel Cell powered vehicle and the electric vehicle.

As mentioned above, hydrogen's low volumetric energy density, difficulty of storage and safety problems, it is more advantageous to provide and use hydrogen on cars as by using onboard method. One of the most suitable methods for this is the delivery of hydrogen and oxygen to the internal combustion engine using an alkaline electrolyser which is low-cost and can be conveniently found in the market. However, there are some studies about H_2O based nanofluids or other type of nanofluids [6–9], there aren't enough study about alkaline based simple water electrolyser which were directly used in internal combustion engines.

Previous studies on the use of hydrogen as supplementary fuel in SI engines are given below.

Elsemary et al. [10] worked about 24%, 26%, 27%, 28%, 29%, 31%, 35%, 37%, 49% hydrogen addition by volume basis on a single cylinder, 4 stroke, SI engine. The effect of the hydrogen ratio was investigated by measuring the thermal efficiency, specific fuel consumption, CO and unburned HC emissions. During the measurements, the engine speed is fixed at 3000 rpm and the ignition time is fixed at 35° BTDC. As a result of the measured values, the emissions and performance of the engine improved with hydrogen addition.

Wang et al. [11] carried out their studies with adding hydrogen to the fuel-air mixture. The hydrogen and oxygen were separately sprayed to the spark-ignition gasoline engine to provide a 2:1 hydrogen-oxygen ratio. The tests were carried out at 1400 rpm engine speed and under intake pressure of 61.5 kPa, with a volume of 0%, 2% and 4% of hydrogen in total intake gas. The air excess coefficient was tested by varying from 1 to the poor burning limit and all characteristics were examined. Hydro-Oxygen additive increased NO_x emissions while reducing HC and CO emissions compared to the original and hydrogen-added operating conditions.

There are also some studies in the literature that investigate the SI engine performance using theoretical model which one of them is given below.

Some researchers [12] studied about air condition effects on the engine power and fuel consumption using GT-Power software and MLP (Multi-Layer Perceptron) neural network.

However, there are some studies which experimentally investigate engine performance, emission and combustion characteristics which one of them are summarized in the next paragraph.

Karagoz et al. [13] investigated the effect of hydrogen addition in SI engine. During the tests, alkaline water containing 10 wt%, 20 wt% and 28 wt% potassium hydroxide was used as the electrolyte. The voltage applied to the electrolyser was controlled between 3.5 and 4.0 V and the inter-planar spacing's were changed between 2 and 10 mm. The tests were carried out at different engine speeds, and the amount of $H_2 + O_2$ produced was selected as 20 l/min and the results were compared with the condition of working without hydrogen. With $H_2 + O_2$ addition exhaust emissions decreased by CO between 3.5% and 16.4%, THC decreased by 24.7% at 2000 rpm.

There are also studies in the literature that examine the effects of hydrogen addition on rotational SI engines, one of which is summarized in the following paragraph.

Su et al. [14] conducted their studies about the effect of ignition timing on hydrogen gasoline fueled Wankel engine. The ratio of hydrogen to volumetric total absorbed gas was changed from 0% to 3% to 6%. At the same time, the amount of gasoline injected to provide stoichiometry has been reduced. Tests have changed the ignition time to be examined from 2 to 24°. The thermal efficiency increased first by increasing the ignition advance and then decreased. HC and CO emissions decreased with the hydrogen ratio. NO_x emissions rise with the increase on hydrogen ratio and ignition advance.

Some studies in the literature have examined the effect of hydrogen on the idle performance and emissions characteristics of using hydrogen as an additional fuel in SI engines.

Chen and Raine [15] performed their research about the effects of hydrogen enrichment on engine operating stability, fuel economy and emissions. They obtained that when increasing the amount of hydrogen, the engine stability was improved. At the same time, they found that the hydrogen addition has a positive effect on emissions and CO and HC emissions.

In addition, there are some studies about the effects of hydrogen addition on natural gas fueled SI engines which are given in the following paragraph.

Yan et al. [16] did a literature survey about SI engines working with HCNG. The physicochemical analysis of the hydrogen and CNG blend has also been searched such by evaluating adiabatic flame speed, auto-ignition temperature, flammability limits etc. Also, they found that the emission and performance of CNG fueled SI engines improved with hydrogen addition.

Gharehghani et al. [17] numerically and experimentally carried out their studies about the effect of different levels of hydrogen addition on emission and performance of the natural gas SI engine. The hydrogen contribution reduced HC, CO and CO_2 emissions while increasing NO_x emissions.

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