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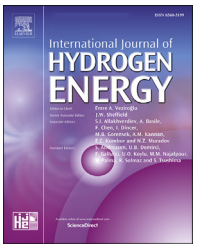

Influence of addition of hydrogen produced on board in the performance of a stationary diesel engine

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ABSTRACT

A stationary diesel engine is tested using HHO produced on board by a commercial electrolytic cell as additive. The cell uses KOH as electrolytic and is connected to the engine battery. Experiments show the cell efficiency is better when current is 6–10 A. Engine was tested in several load regimes, measuring fuel consumption and others parameters, including vibration. Results shows that BSFC and thermal efficiency with HHO improves an average of 3,81% and 2,79% respectively, depending on engine regime and load. Vibration is evaluated using RMS and peak-to-peak values of vibration acceleration, measured in two points on top and one side of the engine. The addition of HHO reduces vibration in most of the experimental points, ought to a better combustion process of gasoil in presence of hydrogen.

Introduction

Hydrogen is a very interesting and well-known option for fueling IC engines; nevertheless, hydrogen internal combustion engines have many challenges to overcome. One of the principal drawback is the production and storage of hydrogen with security and with an affordable cost, due to high-energy demands, need of special materials and the negative effects of hydrogen consumption on some engine components [1–3].

An alternative is to produce small amounts of hydrogen on demand, and use it as an additional fuel, or additive to the main fuel. In this case, storage is not necessary. Generation of hydrogen is possible from a variety of sources such as fossil fuels, biomass, water and some industrial waste chemicals. Among them, water electrolysis is considered a simple and cheap way for obtaining the amount of gas needed, about 4–5% of total world production stem from water electrolysis [4–7].

Electrolysis can be achieved at the expense of electric energy from a battery or the alternator in the own engine. The gas obtained is known as HHO or oxyhydrogen gas, Brown gas, etc.

A lot of information is available for the public domain about the effects on fuel economy of hydrogen on-demand

Abbrevations: HHO, Oxyhydrogen or Brown gas; BSFC, Brake specific fuel consumption; RMS, Root Medium Square.

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systems made for internal combustion engines; a quick search on the internet shows the existence of many car users that have installed commercial or self-made electrolytic devices and claims for extraordinary fuel savings. Nevertheless, there is not always enough scientific evidence proving the economy enhancing effects of on-board HHO production for diesel or spark ignition engines, more exactly some of the articles published also show contradictory results, confirming and rebuffing the positive effects of Brown gas addition.

Khalate [8] claims for saving of 25–45% in fuel using a HHO cell, with battery as energy source. Patel et al. [9] ensures CO and HC emissions shrank and NO_X raises when HHO is mixed with fuel in a CI engine. The battery fed the cell, without information about others parameters. Bhardwaj et al. [10] test a commercial engine with HHO gas mixed with gasoline, but give no data about the proportions. According to Bhardwaj the reduction in BSFC is between 26% and 31%, and the increase in efficiency reaches 27÷31%, the electrolytic cell was fed with external DC supply. Bari [11] evaluated the effect of HHO with diesel in an engine at constant velocity and three different power: 19, 22 and 28 kW. A H_2/O_2 generator and 24 V external power supply produces the Brown gas. The mixture used up to 7% of HHO, about 30 L/min, and is dried before entering in the engine. Results shows improvements in efficiency in all loads, between 6,2% and 4%, and reduction in BSFC of 7,8% to 4,7%. The emissions of CO, CO_2 and HC were reduced, but the NO_X increased, due to the higher flame temperature of hydrogen. Lilik et al. [12] tested a CI engine with external HHO supply, in proportions of 2,5–15% of ordinary fuel on energy bases, and indicates a small reduction in emissions, not for cause of burning HHO, and a modest reduction in engine performance. Adnan et al. [13] experimented in CI engine without modifications, using HHO from a storage tank. Pressure inside cylinder shows a shift to the right and increases maximum value in 5 bar at 2500 rpm. Power increases 4%–16%, exhaust gas temperature and NO_X emissions growths to 2500 rpm and then decreases slightly.

Yilmaz [14] employs an electrolytic cell with NaOH at 1%, producing up to 5 L/min of hydroxy gas with an external PWM DC supply and a diesel engine. This represents a high level of gas production, considering Faraday Law of electrolysis. Results show a relevant increment in torque of 19%, and reductions in BSFC in 14%. Nevertheless, these results are waned by an abnormally high BSFC that reaches 1200–1400 g/kWh, too high for diesel ordinary engines. Roussan [15] uses two different cells in a gasoline engine, one have half the active surface of the other, and externally power supplied. Test were conducted at constant load and different speed from 1000 to 2500 rpm. Results are a better efficiency and reduced BSFC, and a reduction in exhaust gas temperature, ought to a better combustion. Masjuki et al. [16] used HHO as additional fuel with biodiesel, and indicates increments in brake power when HHO is added to both fuels: diesel and biodiesel. The best results are for diesel plus HHO. The same occurs with BSFC, being the biodiesel alone the best, but with penalties in power and torque. Kotan [17] experimented the use of HHO in a CI engine, but give no information about how the cell is fed. HHO is supplied in proportions of 0,2 to 0,8 l/min in the intake of engine and in loads of 40–100% at constant speed. The BSFC is reduced and efficiency improves in all test points, more at low and mediums loads, with average of 3%.

In Birtas et al. [18] is recognized the presence of some quantity of water in the Brown gas, although consider the gas with a stequiometric composition. The engine was a naturally aspirated diesel, the cell was energized externally and gas passed through a silica-gel filter for moisture desiccation. According to the article the engine efficiency decreases slightly, emission is reduced, excluding NO_X, but even NO_X is minor at 40% load with 8% HHO addition. In Shitole et al. [19] a diesel engine in a test bed is proved with 0,6 L/min of HHO added to the fuel. According to the author, the efficiency increases in 13,8%, BSFC decreases in 8,7% at full load, the engine power growths in 6%.

In all the papers above the cell is fed externally respect to the engine, and results are as expected, due to the positive characteristic of hydrogen as a fuel. The amount of supplementary gas in most of the cases not represents a great influence in the volumetric efficiency of the engine.

Kassaby et al. [20] evaluate different proportions of KOH and NaOH in water electrolysis, finding that 6 g/L KOH gives the highest efficiency at different motor speeds. The efficiency of the cell is determined using the inverted probe method, and is near to 42%. This value over exceeds the efficiency according to Faraday, probably due to the presence of water vapors in the gas. The cell produces 18 L/min maximum, possibly with a very high current, not reported by the author. In a gasoline engine at 1500, 2000 and 2500 rpm and different load, the outcomes are an increase in efficiency of 10%, reduction in BSFC of an extraordinary 34%, reduction in emissions, including NO_x in 15%. The engine battery recharged by the engine alternator powers the cell. Rashad [21] reports the use of oxyhydrogen gas in a diesel engine at 5%, 10% and 15% concentration; and currents of 9A, 13 A and 20A. The fuel consumption diminishes in 14% below 40% of load, for loads above this value, no effect is observed. The engine power decreases with HHO, and exhaust gas temperature trends to rise with load, but with values below the obtained with gasoil only. The efficiency growths 20% at low loads only, at a bigger load has no change or even decreases. The author attributes this behavior to the volume of HHO introduced in the engine, which displaces some amount of fresh air in intake manifold.

Kersys et al. [22] evaluate the effects of HHO obtained by water electrolysis in cars engines, three gasoline and three diesel. The cell consumes 25 A and generates 1,8 L/min and uses a current pulse generator and the engine battery for power supply. The addition of HHO reduces emissions in all cases. The impact on fuel consumption was not significant.

Naresh et al. [23] experimented with an electrolytic cell in a diesel engine, using the engine battery for cell power supply. According to them, the engine power increases with Brown gas addition, the efficiency also improves. Following the author benefits from using HHO as an additional fuel can be so good than a reduction in fuel consumption of 25%–45% and even more is possible.

A very interesting information is in Santilli [24] about the characteristic of Brown gas. He outlines several properties of HHO, including the presence of components apart from H and O, possibly a new form of water; the presence of dimmers of HO, and an elevation of flash point in fuel blended with HHO.

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