

## ENCIT-2018-XXX EXPERIMENTAL ANALYSIS IN A DIESEL GENERATOR SET CONSUMING FUEL B7, WITH HHO GAS INJECTION IN THE AIR OF ADMISSION

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**Abstract.** *There is little solid experimental evidence regarding the use of hydrogen formed by water electrolysis (HHO) in internal combustion engines by mixing it with the intake air. This work aims to perform experimental tests on diesel generator set consuming B7 fuel with HHO gas injection in the intake air. The parameters of specific fuel consumption, exhaust emissions and gas temperature were evaluated. The experimental results show that there was a reduction in the specific fuel consumption and increase in the temperature of the exhaust and NOx emissions. The electric current of the electrolytic cell was a parameter used to vary the amount of gas produced by the cell.*

**Keywords:** *water electrolyze, HHO gas, generator set and diesel engine.*

## 1. INTRODUCTION

Issues involving the production and use of viable or renewable targets have been studied in many research centers in Brazil and worldwide. Among the forms of alternative fuels, we have biodiesel, ethanol, hydrogen, vegetable oils, or mixtures with mineral diesel.

The main idea revolves around replacing diesel oil for those that are biodegradable, non-toxic, easy to produce and renewable in nature (Pereira, 2011). Another important point is the study of efforts to improve the efficiency of the processes of combustion of diesel engines, reduction of consumption and fuel consumption.

Approaching alternatives aimed at improve the quality of the combustion process, the work of adding hydrogen gas in the engine intake air has excellent results (Rocha, 2016). Commercial hydrogen is generally used, with a purity of around 99.99%.

Researches are being conducted on the use of hydrogen gas as an auxiliary fuel to improve the combustion process in MCI. These solutions seek to combine the characteristics of the hydrogen gas with the internal combustion engine. This is made possible by the verification of some physical characteristics of physical-hydrogen exercise, among them, the rapid combustion and high PCI which is around 119,972 MJ / kg, (Morais, 2013) and Sandalc and Karagöz (2014).

Although it is the most abundant element in the universe, hydrogen needs to be produced from other sources of energy. There are several routes for the production of hydrogen, such as thermochemical cycles, reform of organic fuels such as natural gas, alcohol, biomass, among others, and the electrolysis of water.

## **2. USE OF HYDROGEN IN ENGINES CONSUMING DIESEL OIL**

The issues surrounding the production and use of fossil or renewable fuels have been studied in many research centers in Brazil and around the world. Among alternative fuels alternatives are biodiesel, ethanol, vegetable oils, or mixtures of these with mineral diesel. Other alternatives aim to improve the efficiency of the combustion process by using the addition of hydrogen gas in the engine intake air (Rocha, 2016).

The search for increased efficiency and performance in compression ignition engines has led researchers to develop several methodologies to achieve these objectives. Among them is the use of hydrogen as an auxiliary fuel to improve the combustion process. Hydrogen is a clean, renewable and recyclable fuel and its use as a fuel reduces the emission of polluting gases by not containing carbon in its composition (the product of combustion is water vapor), improving substantially the air quality (Karagöz et al. al., 2016).

The way the hydrogen gas is injected influences the combustion process. In this work the method of continuous injection of hydrogen in the engine intake air manifold was used, since it is the simplest to be implemented. However when using it, the use of short flame devices is indispensable, which avoids the risk of explosion in the event of backfire. According to Hamdan et al., (2015) this method contributes to the reduction of the volumetric efficiency of the engine.

In the paper presented by Deb et al, 2015, it was shown that emissions of carbon dioxide, carbon monoxide and unburned hydrocarbons were reduced, as was the specific fuel consumption. NOx emissions increased due to the increase in temperature caused by the acceleration of combustion during the burning of hydrogen.

Karagöz et al. (2016) found reductions in CO, CO<sub>2</sub> and HC emissions and increase in NOx emissions, when using tests with the injection of hydrogen gas in an internal combustion engine. The results showed that there was an increase in the specific fuel consumption, a fact that was associated to the reduction of the volumetric efficiency of the engine, caused by the injection of hydrogen into the air intake manifold.

### **2.1. Experiments performed using HHO gas in internal combustion engines**

Among the work that used and burned the hydrogen contained in the HHO gas, produced by the process of electrolyzing water to improve the performance of the engines, we have developed by Musmar and Al-Rousan (2011). They developed an HHO gas generation system produced by two cells that was connected directly to the engine. They resulted in an increase in thermal efficiency by about 3% for B cell and 8% for C cell. There was also a reduction in specific fuel consumption.

In the work done by Rajaram et al. (2014), the influence of the addition of oxygen enriched with HHO gas in a direct injection diesel engine was verified. The main parameters analyzed were: the thermal efficiency to the brake and emissions. The results showed that by introducing HHO gas, thermal efficiency at the engine brake increased by 11.06%, carbon monoxide decreased by 15.38%, unburned hydrocarbons decreased by 18.18% and carbon dioxide increased in 6.06%.

In their research, Sur et al. (2014) verified changes in the use of HHO gas in a single-cylinder gasoline engine of 5.4kw, 8000rpm rotation and 8.8: 1 compression ratio. The results showed that there was reduction in specific fuel consumption. In addition, there was also the reduction in CO emissions, characterizing greater combustion efficiency.

## **3. EXPERIMENTAL APPARATUS**

To carry out the tests using the HHO kit and the B7 fuel was set up a bench made up of a diesel generator set, measuring instruments (thermocouples, digital scale, anemometer, gas analyzers and electric magnitude meter) and data acquisition system. For each test, the following parameters were evaluated: volumetric and fuel mass flow, electric power, exhaust emissions and exhaust gas temperature.

To perform the tests, a single-cylinder engine generator set BRANCO BD-6500 CF3E four-stroke engine, air-cooled and direct fuel injection was used. The generator was connected to a 5kW resistor bank that is used to vary the electric charge. For the tests, a power of 60% of the nominal load of the generator set was used. The electrical quantities were monitored using the SAGA 4500 equipment, which measures electric current, active and reactive power, power factor and electrical voltage.

For the monitoring of the mass flow of fuel consumed by the engine a precision digital scale was used. Based on the information on the fuel mass flow and the electric power generated, the specific fuel consumption ( $C_{spc}$ ) was calculated as shown in equation 1.

$$C_{spc} = \frac{\dot{m}_{B7}}{P_{ele}} \quad (1)$$

Temperature monitoring at various points in the generator set was carried out using K-type thermocouples. A Greeline 8000 gas analyzer was used to measure the exhaust gases. It is possible to measure CO, CO<sub>2</sub>, O<sub>2</sub>, NO<sub>2</sub>, NO and HC. The mass flow rate of HHO gas produced by the hydrogen cell was measured using an Omega brand rotmeter. For the mass flow of air of the engine, a turbine-type anemometer was installed in a hose that was connected to the air box installed in the intake pipe.

For the acquisition and treatment of the data sent by the data acquirer, it was necessary to create a computational supervisory and control tool, developed with the help of the DAQFactory Pro program. V16.2.

### 3.1. Test Experimental Methodology

Initially a test was performed on the generator set operating only with B7. Measurements were made in the fuel mass flow, temperatures, emissions and electrical power, to generate a baseline that will serve as a comparison for the results obtained with the injection of HHO gas. Figure 1 shows a schematic of the experimental bench, located in the Motors Laboratory, at the Faculty of Mechanical Engineering, Federal University of Pará, where the tests were performed.

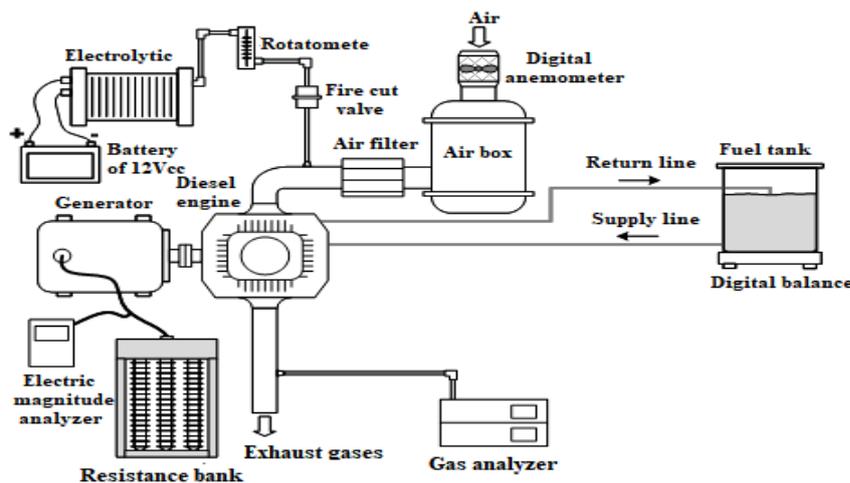


Figure 1. Scheme of experimental bench of tests

When connected to the cell, the current supply can be varied from 10A, 20A, 25A and 30A via the current controller.

The analysis of the motor operating parameters was performed based on the current of the cell. The ideal would be to perform a gas analysis with the use of a chromatograph, however we do not have such equipment.

The HHO gas was injected into the intake air of the engine, while the information on fuel consumption, electric power, emissions and gas temperature was collected to be compared with the base line of the engine operating only with B7.

For all tests performed on the generator set, a load of 60% of the nominal power (2.43 kW) was used at a rotation of 3600 rpm. In order to guarantee the reliability of the tests, the tests in the generator set were repeated three times for each amount of injected HHO gas using B7 diesel.

The uncertainty was calculated applying the same method used by DEB, SASTRY (2015) and the results are presented in Table 1.

Parameters	Uncertainties
Electric power	±1,00%
Variation of fuel mass	±1,30%

<b>NOx</b>	$\pm 1,08\%$
<b>Gas temperature</b>	$\pm 0,40\%$
<b>B7 mass flow rate</b>	$\pm 1,39\%$
<b>Specific fuel consumption</b>	$\pm 1,92\%$

Table 1. Average uncertainty of the measured and calculated parameters

#### 4. RESULTS

An important point for the development of the project was to identify the physico-chemical properties of B7 diesel oil. Table 2 shows the main properties of B7 and H2. The experimental analysis of these fuels was carried out by the Laboratory of Characterization of Fuels (LacBio), Federal University of Pará.

Properties	B7	Hydrogen
<b>Chemical formula</b>	$C_{6,95}H_{14,79}O_{0,05}S_{0,03}$	H <sub>2</sub>
<b>Density at 20°C [kg/m<sup>3</sup>]</b>	872.7	0,082
<b>Viscosity at 40°C [cSt]</b>	2.9	-
<b>PCS [MJ/kg]</b>	44.0	141,80
<b>PCI [MJ/kg]</b>	41.7	119,97
<b>Elementary Analysis</b>		
<b>C [%]</b>	83.43	
<b>H [%]</b>	14.91	99,99
<b>O [%]</b>	0.79	
<b>N [%]</b>	0.00	
<b>S [%]</b>	0.84	

Table 2. Properties of B7 fuel and H2 gas

The values of the specific fuel consumption were 455.4 g / kWh when only B7 and 437.3, 428.4, 420.2 and 410.6 g / kWh respectively were used for the four values of electric current. In this study, as shown in figure 2, the specific fuel consumption was favorably affected by the increase in electric current, promoting reductions of 3.97%, 5.92%, 7.72% and 9.83%, respectively. Similar results in relation to the specific consumption were found in the studies of HAMDAN, SELIM (2015) and DEB, SASTRY (2015).

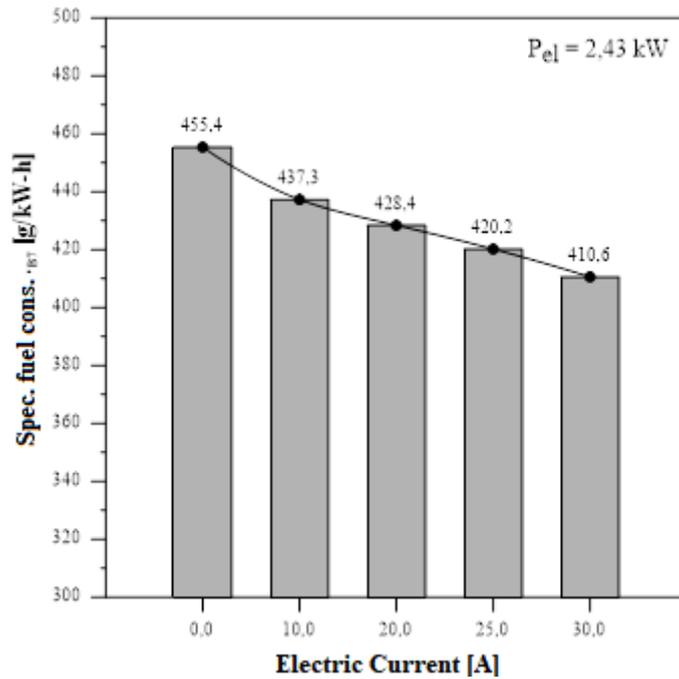


Figure 2. Specific fuel consumption as a function of the electric current

As expected, the increase in electric current caused an increase in the production of HHO gas, consequently the amount of hydrogen gas, which reflects in the increase of the average temperature of the gas in the cylinder, causing increase of the temperature of the exhaust gases. Compared to pure B7, temperatures increased by about 1.85, 5.13, 6.77 and 10.09% respectively (figure 3). These results are compatible with those identified in the works of HAMDAN, SELIM (2015) and MORSY, EL-LEATHY (2015)

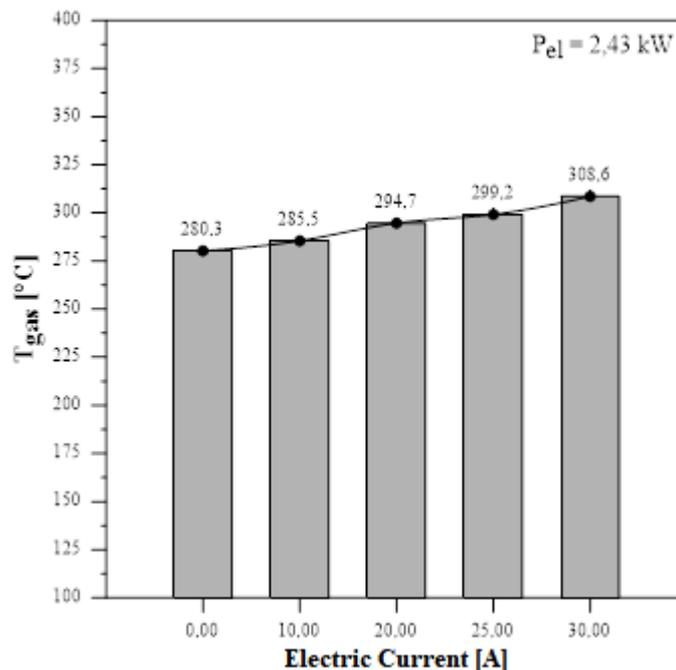


Figure 3. Exhaust gas temperature as a function of the electric current

Figure 4 shows that for the 10, 20, 25 and 30A current variations, nitrogen oxides emissions increased by 5.37, 7.83, 10.48 and 15.26% respectively. The results are similar to those reported by DEB, SASTRY (2015), JHANG, CHEN (2016) and CHIRIAC and APOSTOLESCU (2013).

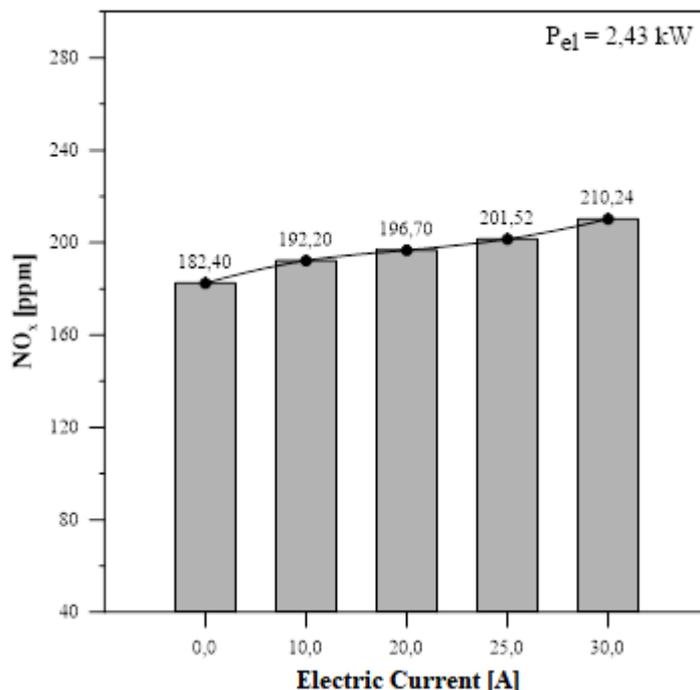


Figure 4. NO<sub>x</sub> as a function of the electric current

## 5. CONCLUSION

After the design and construction of the electrolytic cell for the production of HHO gas, it was tested and the gas produced was found to be combustible. Then small amounts of HHO gas, which represent significant energy fractions of the fuel mixture, were added to the B7 to verify their effects on the performance and emissions of a diesel generator set. This study showed that even a small amount of HHO gas can alter engine performance and emissions. The addition of HHO gas tends to improve the performance of the engine by reducing its specific fuel consumption and its emissions of CO, CO<sub>2</sub> and consequently of HC (since in the composition of the HHO does not contain the element carbon) to values lower than the percentages obtained with the baseline using only B7.

The electric current was used as a parameter to vary the amount of HHO gas to be injected into the engine. The increase in the amount of gas tends to raise and anticipate the pressure peak inside the cylinder, also raising the average temperature of the gases inside the cylinder, which reflects in the increase of NO<sub>x</sub> emissions, where this condition can be aggravated in loads the engine. All this indicates that the hydrogen present in the HHO gas tends to promote faster combustion with higher rates of heat release.

A point to highlight in this work is that HHO gas was introduced into the air intake manifold continuously, without performing any modification or installation of complex equipment in the engine.

## 6. ACKNOWLEDGEMENTS

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## 7. REFERENCES

- Al-Rousan, A. A. Reduction of fuel consumption in gasoline engines by introducing HHO gas into intake manifold. *International Journal of Hydrogen Energy*, v. 35, n. 23, p. 129301-12935, 2010.
- Chiriac, R.; Apostolescu, N. "Emissions of a diesel engine using B20 and effects of hydrogen addition". *International Journal of Hydrogen Energy*, v. 38, n. 30, p. 13453-13462, 2013.
- Deb, M., et al., 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. *International Journal of Hydrogen Energy*, 2015. 40(27): p. 8586-8598.

- Deb, M.; Sastry, G. R. K.; Bose, P. K.; Banerjee, R. "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". *International Journal of Hydrogen Energy*, v. 40, n. 27, p. 8586-8598, 2015. emissions from a heavy-duty diesel engine by using hydrogen additions". *Fuel*, v. 172, p. 89-95, 2016.
- Hamdan, M.O., et al., Hydrogen supplement co-combustion with diesel in compression ignition engine. *Renewable Energy*, 2015. 82: p. 54-60.
- Jhang, S.-R.; Chen, K.-S.; Lin, S.-L.; Lin, Y.-C.; Cheng, W. L. "Reducing pollutant emissions from a heavy-duty diesel engine by using hydrogen additions". *Fuel*, v. 172, p. 89-95, 2016.
- Karagöz, Y.; Güler, İ.; Sandalci, T.; Yüksek, L.; Dalkılıç, A. S. "Effect of hydrogen enrichment on combustion characteristics, emissions and performance of a diesel engine". *International Journal of Hydrogen Energy*, v. 41, n. 1, p. 656-665, 2016.
- Moraes, A. M; Justino, M. A. M; Osmano Souza Valente, Sergio de Morais Hanriot, José Ricardo Sodré. "Hydrogen impacts on performance and CO<sub>2</sub> emissions from a diesel power generator". *International journal of hydrogen energy* v. 38 p. 6857-6864, 2013.
- Morsy, M.H., A.M. El-Leathy, and A. Hepbasli, An Experimental Study on the Performance and Emission Assessment of a Hydrogen/Diesel Fueled Engine. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, 2015. 37(3): p. 254-264.
- Musmar, S. E. A.; AL-ROUSAN, A. A. Effect of HHO gas on combustion emissions in gasoline engines. *Fuel*, v. 90, n. 10, p. 3066-3070, 2011.
- Pereira, R. S. "Evaluation and performance of indirect injection engine consuming palm oil in natura". Masters dissertation. Belém/Pará. UFPA/FEM 2016.
- Rajaram, P. S.; KANDASAMY, A.; REMIGIOUS, P. A. Effectiveness of oxygen enriched hydrogen-HHO gas addition on direct injection diesel engine performance, emission and combustion characteristics. *Thermal Science*, v. 18, p. 259-268, 2014.
- Rocha, Hendrick Maxil Zárate. "Determination of the effects of the use of hydrogen in diesel generator sets operating with different diesel-vegetable oil mixtures!". Hendrick Maxil Zárate Rocha. – Rio de Janeiro: UFRJ/COPPE, 2016
- Sandalci, T. and Y. Karagöz, Experimental investigation of the combustion characteristics, emissions and performance of hydrogen port fuel injection in a diesel engine. *International Journal of Hydrogen Energy*, 2014. 39(32): p. 18480-18489.
- Sur, A. A.; WALKE, P. R.; BASAVARAJ, M. Performance analysis of mono cylinder four stroke spark ignition engine by utilizing green gas (HHO gas) as a fuel supplement. *Golden Research Thoughts*, v. 3, n. 11, 2014.

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