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# DEVELOPMENT OF A MONITORING SYSTEM APPLIED TO A DIESEL GENERATOR WITH ELECTROLYSIS GAS INJECTION FOR REDUCING FUEL CONSUMPTION

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**Abstract.** *This work presents the development of a monitoring system applied to a diesel generator with the injection of electrolysis gas, in order to reduce the consumption of diesel oil in the generator. Diesel fuel is the main fuel and hydrogen is the secondary fuel (additive), injected together with the intake air. This experimental study consists initially of characterizing a hydrogen-generating device (dry cell) through the evaluation of the gas volumetric flowrate produced as a function of the electric current applied to the system and of the electrolyte concentration. Monitoring is performed through an interface that allows information, alerts, and commands to be made available to the user to interact with the automation system and equipment. The cell, engine, and generator monitoring system are developed in Arduino platform, Platform IO, and Visual Studio. The variables of the electrolytic cell (temperature, current, and voltage), engine (consumption, and speed) and generator (power, current, and voltage) are monitored. The main results showed the reduction between 2.4% and 3.25% in the main fuel consumption due to the injection of hydrogen in the diesel oil.*

**Keywords:** *Energy, Hydrogen, Electrolysis, Diesel Generator, Monitoring System, Arduino, C Sharp.*

## 1. INTRODUCTION

With the exponential growth of the world population, high-energy consumption, especially in emerging countries, and the excessive use of fossil fuels, there is a need for energy alternatives to supply future generations. However, the solution to this energy crisis must be linked to the reduction of the environmental impact that accompanies the energy generation (Momirlan and Veziroglu, 2005).

Due to the trend of fossil fuels depletion and rising oil prices, engine manufacturers around the world are encouraged to find alternative approaches to increase fuel economy and reduce environmentally harmful emissions from internal combustion engines (Bari and Esmaeil, 2010).

Some processes can produce hydrogen, as an alternative source of energy, such as electrolysis, thermal decomposition, steam or autothermal reform and thermochemical and biological cycles. Obtaining hydrogen by electrolysis of water generates only pure hydrogen and oxygen (hydrogen in greater proportion) as products, and therefore, the electrolysis gas is a gas rich in hydrogen. Consequently, the environmental impact in this form of production is indirect (LeRoy, Janjua, Renaud, 2012). Among the electrolytes currently used, potassium hydroxide (KOH) has wide application in industrial electrolytic cells as a conducting medium (Onda et al., 2004).

Many studies suggest that the addition of small amounts of hydrogen in the combustion process can reduce greenhouse gas emissions, improve performance and reduce diesel consumption in compression-ignition engines (Bari and Esmaeil, 2010). Such an approach makes the possibility of adapting engines already on the market in order to increase their efficiency and thereby reduce the environmental impacts of using petroleum-based fuels, but without the need to replace already widely used technology. Likewise, directing the gradual development of alternatives to fossil fuels creates a viable transition scenario, where the research and development of products and patents should be

encouraged in a decentralized manner aiming at greater accessibility and simplicity of practical solutions (Zhou et al., 2016).

The present work presents the development of a monitoring system applied to a diesel generator with electrolysis gas injection. The study is of an experimental nature and consists, initially, of characterizing a hydrogen-generating device, through the evaluation of the gas volumetric flow produced as a function of the voltage and electric current applied to the system and the electrolyte concentration. After this study, the hydrogen-rich gas produced was used in a diesel generator, and its performance parameters, such as diesel consumption and power produced, were monitored and analyzed.

## 2. THEORY

Studies on the use of electrolysis gases in internal combustion engines have been conducted since 1918, when Charles H. Frazer received the first patent for a hydro-oxygen generator (Frazer, 1918). This technology became more widely known in the scientific community since 1974 when the On-Board Hydrogen Generator for the Partial Hydrogen Injection Internal Combustion Engine published by the Society of Engineers of Mobility (SAE) stated that the addition of hydrogen, from the on-demand generation electrolysis process, in internal combustion engines is effective with any fossil fuel (Houseman and Cerini, 1974).

The particular process that breaks the water molecule by applying an electric current in hydrogen and oxygen is called water electrolysis. It is defined as a chemical reaction triggered from an external energy source to the chemical system (Badwal; Giddey; Ciacchi, 2006).

The use of hydrogen as an additive in diesel combustion engines was investigated. Saravanan et al. (2008) used hydrogen as an additive, being injected in small-scale constant flow (liters/min) from electrolysis. The authors studied the performance parameters of a diesel engine with and without the hydrogen gas injection system. They evaluated the influence of the addition of different proportions of hydrogen on the performance of a diesel engine. They concluded that there was an increase in thermal efficiency, engine power and a corresponding reduction in main fuel consumption. In addition, Kumar, Ramesh and Nagalingam (2003) observed a reduction in the emission of pollutant gases when using hydrogen as an additive. Mohon et al. (2010) also reported similar results using hydrogen as a fuel additive in diesel engines.

Hydrogen as an additive to improve the performance of conventional diesel engine has been investigated by other researchers and the results are promising. However, the problems associated with the production and storage of pure hydrogen currently limit the application of pure hydrogen in the operation of the diesel engine (Vinayak et al., 2014). Most of the published work focuses on the use of pure hydrogen as an additive and takes into account the problem of hydrogen storage. The use of a hydrogen-oxygen generator, which produces the H<sub>2</sub>/O<sub>2</sub> mixture through water electrolysis, has significant potential to overcome these problems (Mohon et al., 2010).

## 3. METHODOLOGY

The methodology was based on the development of the monitoring system applied to a diesel generator with electrolysis gas injection. The materials used were a dry electrolytic cell, and a 3.75 KVA Diesel Power Generator (single phase, manual start, ND3200, single cylinder, power of 7 HP / 3600RPM, displacement of 296cc, capacity of the 15-liter tank). The monitoring system was developed through Arduino, Platform IO and Visual Studio platforms.

Initially, the characterization of the hydrogen-generating device is carried out through the evaluation of the volumetric flowrate of gas produced as a function of the electric current, the electrolyte concentration and the system temperature. After characterization, the gas-produced rich in hydrogen is used in a diesel engine coupled to a generator to produce electricity. The variables of the electrolytic cell (temperature, continuous current and voltage), engine (consumption, rotation) and generator (power, alternating current and voltage) are monitored.

For this study a test bench (Fig. 1) was built with a diesel generator, an electrolytic cell, using potassium hydroxide (KOH) as the electrolyte, a current source DC 20A and 30V FA-2030 from Instrutherm; an electrolysis gas meter; filters; safety valve; hall effect current sensors, flowrate, rotation and temperature. A 20x4 LCD display, where the main menu is arranged with the options "HHO Cell", "Diesel Engine" and "Generator"; a supervisory interface for system monitoring that was developed in Visual Studio 2013 to receive data from the Arduino via the USB port. The algorithms of moving averages as well as the readings of temperature, current, voltage, flow, rotation, power and power consumption sensors were implemented in the supervisors.

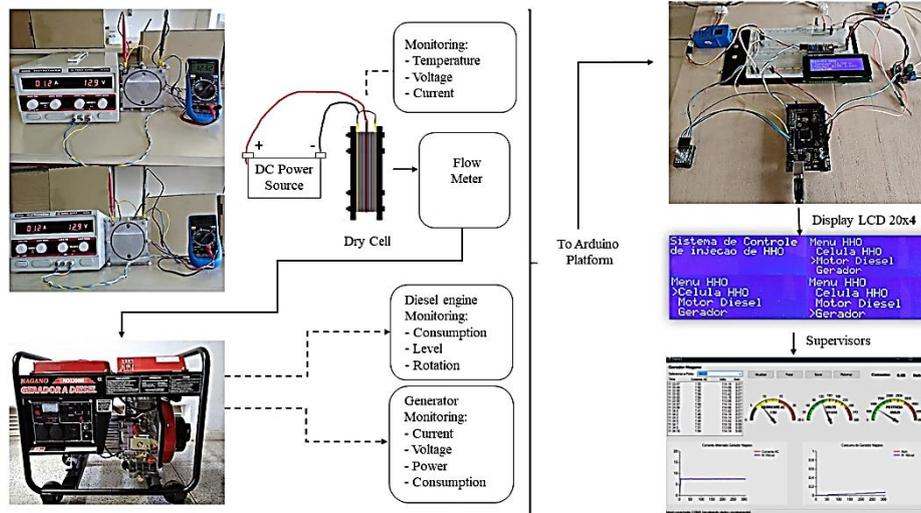


Figure 1 – Test bench showing the monitoring system.

The production of the electrolysis gas by the electrolytic cell was measured using a gas meter consisting of two communicating vessels (one graduated). One of the vessels is open to the atmosphere and the other is connected to the outlet of the electrolytic cell and closed to the atmosphere. Thus, the time for the displacement of 100 ml of liquid was measured because of the production of electrolysis gas. Thus, the volumetric flowrate of the produced electrolysis gas is obtained, as shown in Fig.2.

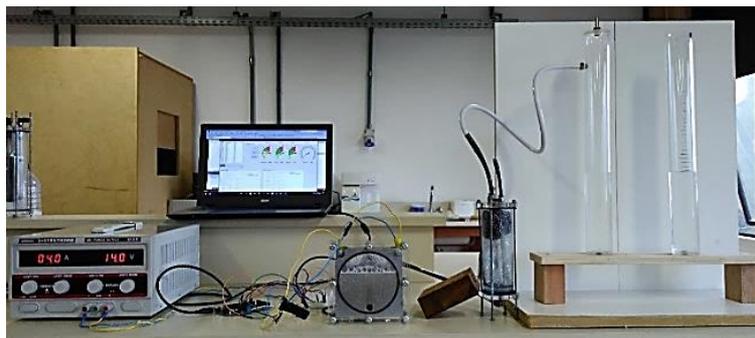


Figure 2 – Test bench with dry electrolyte cell.

The sensor YF-S402, turbine type and hall effect, was used to measure the instantaneous fuel flowrate in the internal combustion engine. This flow sensor is composed of a small turbine whose output signal is a series of digital pulses. The pulse frequency is proportional to the liquid passing through the sensor. This digital signal can be read directly through one of the digital input / output pins of an Arduino. The calibration of the YF-S402 flow sensor was performed as a function of pulse numbers for different fuel amounts. The frequency of the pulses is proportional to the liquid velocity passing through the sensor, so the pulses will be counted enabling an Arduino interruption. Initially, the diesel fuel amount was gradually raised from 50 mL to 1000 mL, with a 50mL to 50mL step. Figure 3 shows the graph plotted and by linear regression, the calibration curve was obtained.

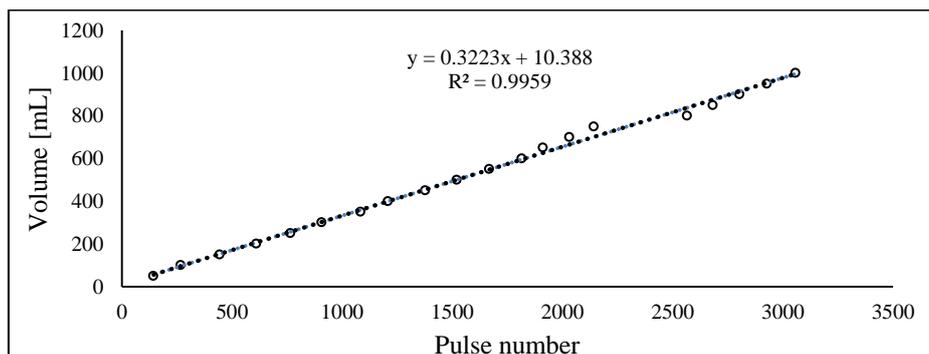


Figure 3 - YF-S402 sensor calibration curve.

The volumetric flow calculation of the work can be done through Equation (1).

$$Q = V/t \tag{1}$$

Where:  $Q$  is the fluid volumetric flowrate [ $m^3/s$ ],  $V$  is the diesel volume [ $m^3$ ] and  $t$  is the time [ $s$ ]. The diesel fuel volume, Eq. (2), is calculated by means of the linear regression obtained from Figure 3.

$$V = (P \times 0.3223) + 10.338 \tag{2}$$

Where:  $P$  is the number of pulses measured by the sensor.

To measure the engine speed, it was necessary to construct a tachometer using a TCRT5000 reflective optical sensor. It has an infrared sensor (emitter) and a phototransistor (receiver) coupled to the same device. In addition, a comparator integrated circuit was used to make comparisons between the supply voltage (5 volts) and the voltage generated by opening the light path to the phototransistor, generating a square wave signal at the output ranging from zero to five volts.

An aluminum strip was glued to the flywheel of the motor, as shown in Fig. 4, to reflect the light provided by the LED to the phototransistor, thereby generating an optical pulse train that is converted into an electrical signal by the opto-electronic circuit. Four markings were used with the aluminum strips to improve the resolution of the rotation frequency reading.



Figure 4 - Installation of the TCRT 5000 sensor on the flywheel of the diesel engine.

The engine speed calculation was implemented in the Arduino's firmware by external interruption, with four interruptions equal to one engine speed. In this way, you can calculate the engine speed through Equation (3).

$$Rotation = (counter/m) \times 60 \tag{3}$$

Where: *counter* is number of interrupts and  $m$  is the number is fixed markings on the engine flywheel.

Figure 5 illustrates the schematic diagram of the overall design of the research project. The main difference between this proposal and the works presented in the consulted literature is the implementation of the monitoring system, illustrated in dashed lines.

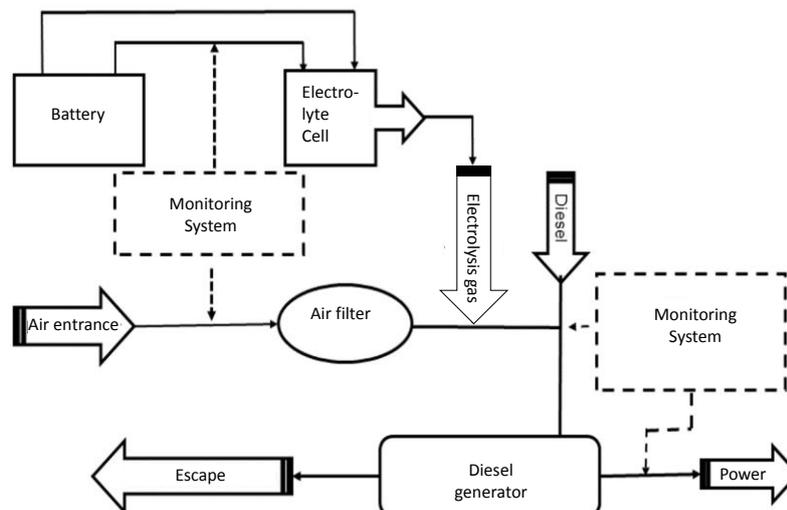


Figure 5 - Schematic diagram showing the monitoring system implemented.

For the development of the interface, the 20x4 LCD was used. It contains a home screen with the main menu presents the equipment "HHO Cell", "Diesel Engine" and "Generator"; and the submenu of Fig. 6 shows the variable information of each sensor of the electrolytic cell, diesel engine and the monitor monitored in real time.

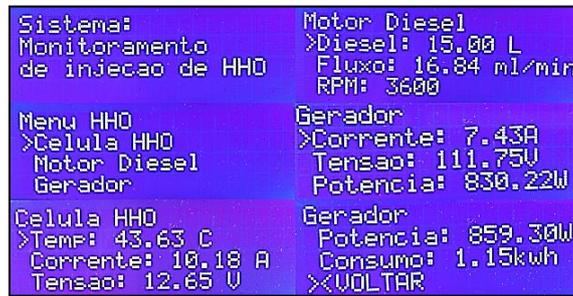
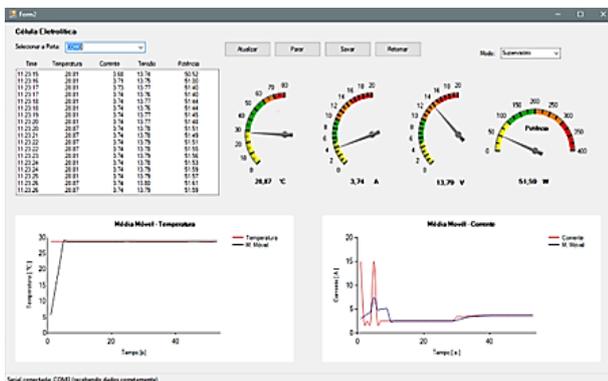


Figure 6 - Submenu found in each experiment kit.

For monitoring, the system was developed in Visual Studio 2013 to supervisory program in the language C Sharp, to receive the data of the Arduino, through the USB port. Figure 7a shows the electrolytic code interface that shows the graphs with temperature [°C] versus time [s] and current [A] versus time [s], and the moving average. You can also get the values of temperature, current, voltage and power. Just like two graphs, the one on the right shows the instantaneous value of the temperature and of the moving average. The right graph shows the instantaneous current value and the measure of moving average of cell performance. Figure 7b illustrates the diesel engine supervisor interface that the algorithms of moving averages, diesel instantaneous consumption and motor rotation were implemented. Thus, the graph on the left shows the instantaneous value of diesel consumption and its moving average. The graph to the right shows the instantaneous value of the motor rotation and the moving average accompanying the value. Also monitoring the consumption and the rotation of the motor through the interface. Figure 7c displays the generator interface, where data from current and voltage sensor readings at generator output, as well as power and power consumption calculations are made available. Moving averages of current and energy consumption were implemented. You can check the graph on the left that shows the instantaneous value of the generator current and its moving average. The graph to the right shows the instantaneous value of the generator's energy consumption and the moving average accompanying the value.



(a)

(b)



(c)

Figure 7 - Supervisor: (a) Electrolytic Cell Interface, (b) Diesel Engine Interface, (c) Generator Interface.

## 4. RESULTS AND DISCUSSIONS

### 4.1 Eletrolysis gas analysis

To analyze the composition of the electrolysis gas samples, a gas chromatograph was used, Shimadzu, model GC, series 2014. The analyzes were carried out through a Flame Ionization Dectector (FID) and a capillary column of 30 m (GC - GASPRO) with an internal diameter of 0.32 mm. GC injections were performed with a sampling valve (Valco E60) with a sampling loop of 250  $\mu$ L. The gaseous samples were collected directly from the electrolytic cell, each electrolysis gas sample containing 250  $\mu$ L. Concentrations of 15.0 g/L and 17.5 g/L of KOH were used for the electrolytic solution. The system current was gradually raised from 1 A to 10 A, with a 2 in 2 A step, applied to the electrolytic cell in order to measure the electrolysis gas concentration. Figure 8 shows the values of hydrogen concentrations resulting from the chromatographic analysis of the electrolysis gas samples.

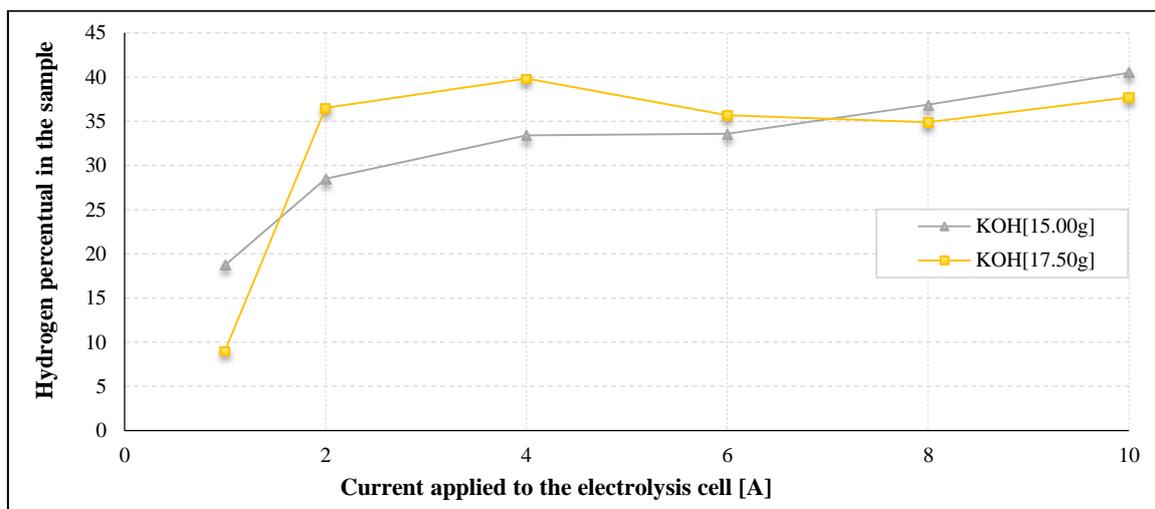


Figure 8 - Hydrogen concentration produced *versus* current applied and electrolyte concentration.

It can be observed in Fig. 8 that the variation of the electrolyte concentration and the current applied to the electrolysis cell induces the increase in the hydrogen concentration produced. According to Figure 8, the point of greatest hydrogen production (approximately 40%) occurs when the concentration is 17.5 g/L KOH and the current is approximately 4 A. Another point to be observed is the behavior of the 17.5 g/L KOH curve, where the maximum inflection point of the curve occurs at low current while at the concentration of 15.0 g/L KOH, the maximum proportion of produced hydrogen, which was 40%, would have the current consumption of 10 A, which can penalize the system as a whole.

### 4.2 Electrolysis Gas Production in the Electrolysis Cell

The electrolysis gas production by the electrolysis cell was performed using the gas flowmeter. Concentrations of 10.0 g, 12.5 g, 15.0 g, 17.5 g and 20.0 g KOH were used for 1000 mL of water for the electrolytic solution. The system current was gradually raised from 1 A to 10 A, with a 1 in 1 A step, applied to the electrolytic cell in order to measure the electrolysis gas flow rate, temperature and power consumed.

Figure 9 shows the results of electrolysis gas production as a function of the current applied at the KOH concentrations reported. From Fig. 9, it can be observed that with the increase of the applied current and the electrolyte concentration, the electrolysis gas production also increases. 10.0 g/L KOH shows the lowest production of electrolysis gas as well as 20.0 g/L KOH concentration shows the highest electrolysis production of the reported current range. The average percentage difference between these two concentrations was 33.2%, presenting a greater difference in the current of 1 A (around 68%), with an electrolysis gas production of 19 mL/min for the concentration of 10.0 g/L and 32 mL/min for the KOH concentration of 20.0 g/L. The intermediate concentrations present very close percentage differences showing average differences around 2%.

Figure 10 shows the electrolytic cell temperature variation with the applied current. From Fig. 10, it is observed that with increasing current, the temperature also increases. At the 10.0 g/L KOH concentration, the temperature did not exceed 35°C. At the 12.50 g/L KOH concentration, there was an increase in temperature by 14% and at the 15.00 g/L KOH concentration; there was an increase in temperature by 19%. For the concentrations of 17.50 g/L and 20.00 g/L there was an increase in temperature of 12.5% and 24.5% respectively, (especially when the current reached values

above 10 A), both compared to that of 10.00 g/L KOH. This heating translates into energy losses since the energy as well can damage the materials constituent of the electrolytic cell and decrease the electrolysis gas flowrate.

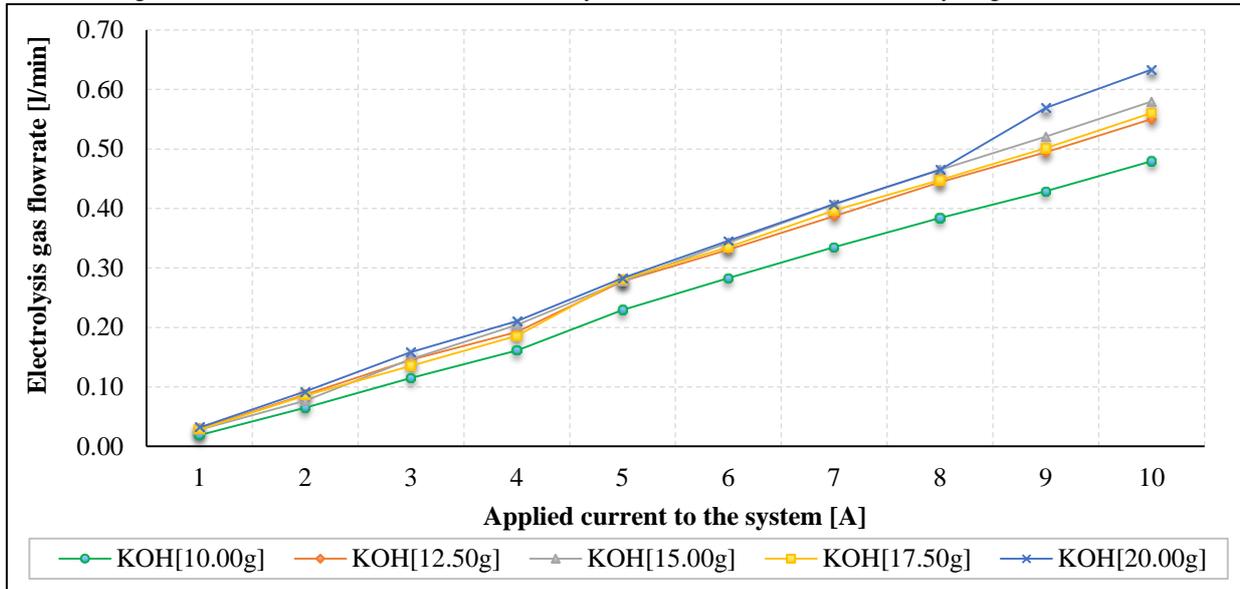


Figure 9 – Electrolysis gas production of as a function of the current applied at the KOH concentrations reported.

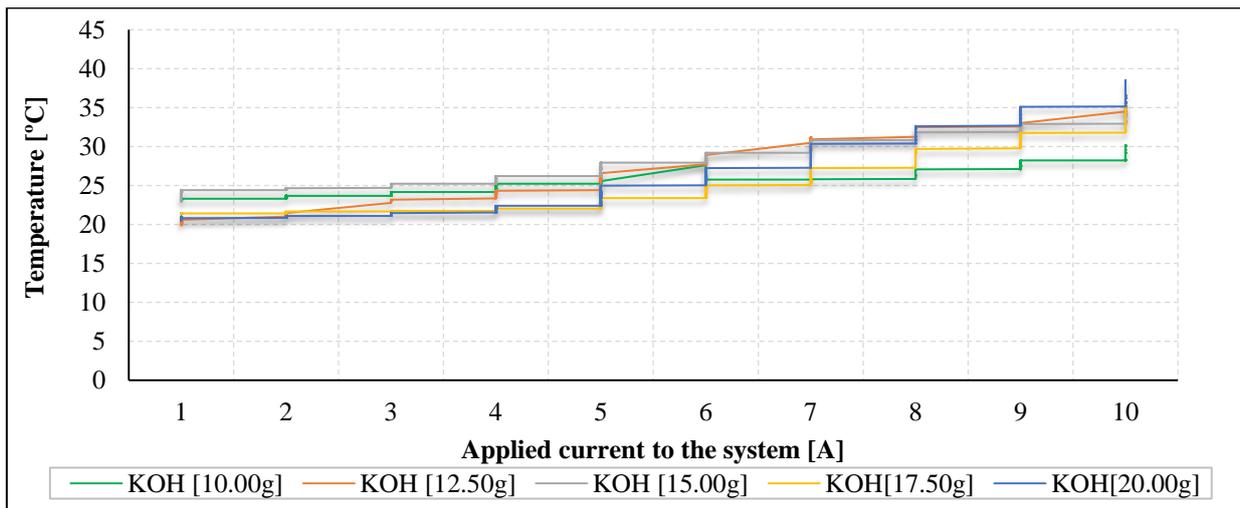


Figure 10 – The electrolytic cell temperature results as a function of the applied current.

Figure 11 shows the electrolysis cell voltage variation with the applied current.

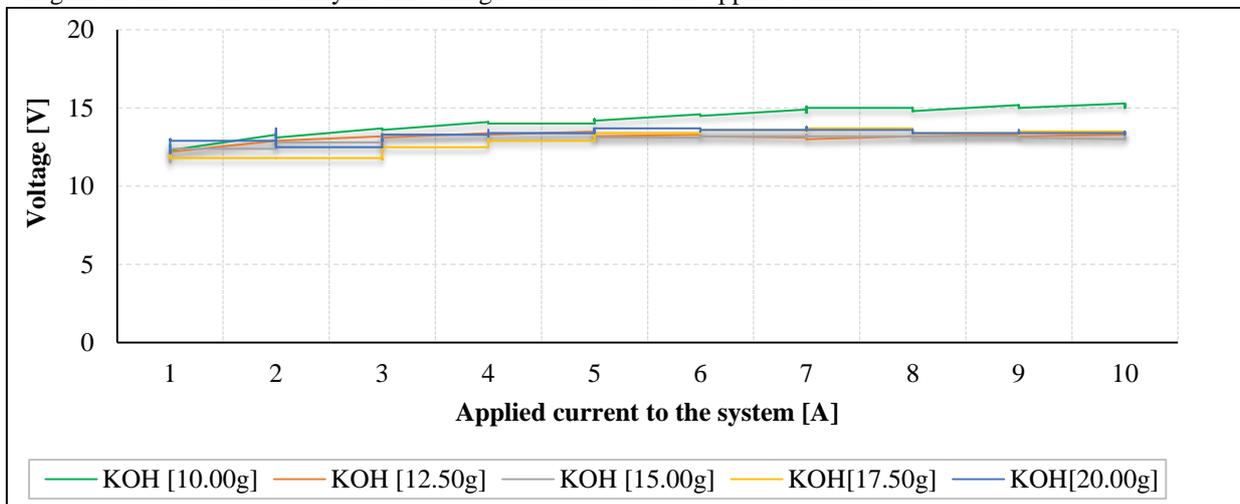


Figure 11 – Electrolysis cell voltage results as a function of the applied current.

It can be observed from Fig. 11, the increase in current also increase the voltage applied in the electrolysis cell. The concentration of 10.0 g/L shows the highest voltage in the electrolytic cell, in the current range 1 A to 10 A. The mean percentage difference between the concentration of 10.0 g/L and the other concentrations was around 12%. For the concentrations of (12.5 g, 15.0 g, 17.50 g and 20.00 g KOH), the mean value of the voltage was 12.9 V.

### 4.3 Diesel generator

A 1 kW load test was performed at the diesel generator output for the monitoring of diesel consumption and rotation, using the concentrations of 17.5 g/L and 20.0 g/L of KOH, for approximately one hour. Figure 12 shows the results of diesel consumption.

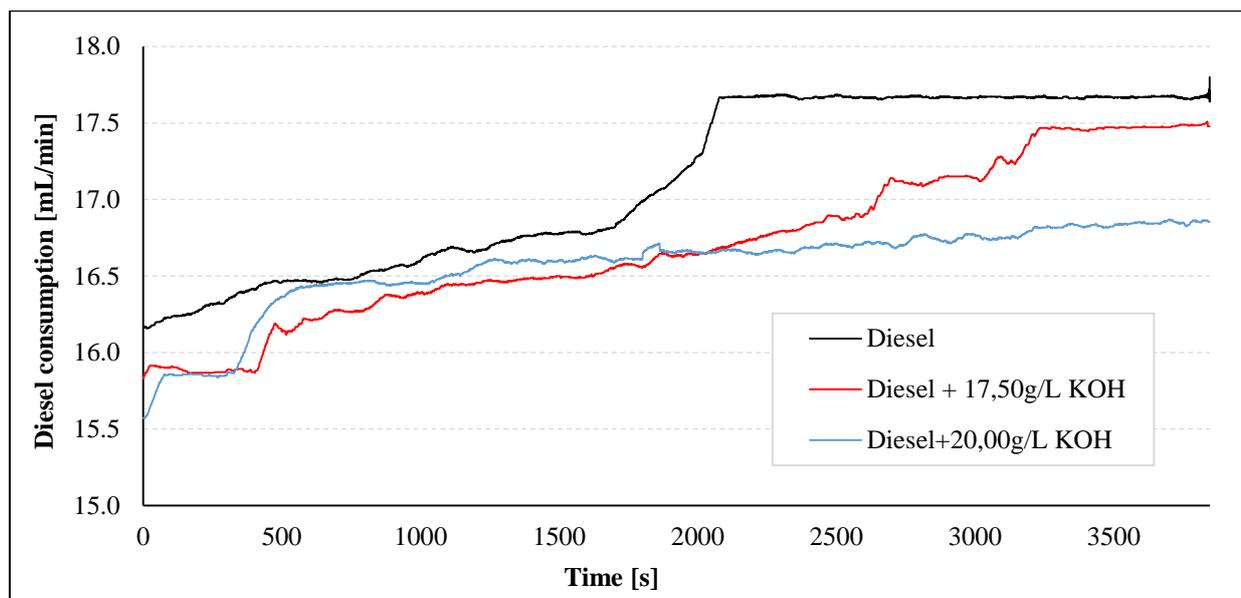


Figure 12 – Results of diesel consumption of the generator versus time.

According to Figure 12, it can be observed that the average percentage reduction between diesel consumption and the addition of the electrolysis gas, at a concentration of 17.5 g/L, was around 2.40%. At the concentration of 20.0 g/L, the reduction in consumption was 3.25%. The speed of rotation of the motor generator was monitored during the tests and remains constant at 3600 and 3660 rpm, without and with the load of 1kW, respectively.

## 5. CONCLUSION AND DISCUSSION

This work presented an experimental study on the development of a monitoring system applied to a diesel generator with the injection of electrolysis gas in order to verify the influence of the electrolysis gas on the engine performance parameters. This work consisted of two phases: (i) evaluation of the electrolysis gas production and (ii) evaluation of the performance parameters of a diesel engine. Diesel is the main fuel and hydrogen is the secondary fuel (additive), injected together with the intake air. The development of the monitoring system was of great importance to evaluate the parameters that most influence the process of generating a hydrogen rich gas (electrolysis gas) and to monitor the performance parameters of an internal diesel combustion engine coupled to an electrical generator.

The gas chromatographic analyzes performed for the KOH concentrations of 15.0 g/L and 17.5 g/L showed that there was a higher volume of hydrogen rich gas at the concentration of 17.5 g/L, which represents a 40% increase over the concentration of 15.0 g/L. In addition, the increase in the current applied to the system showed an increase in temperature and voltage. For the concentration of 10.0 g/L of KOH, the temperature did not exceed 35°C. At the concentration of 12.50 g/L and 15.00 g/L of KOH, there was an increase in temperature by 14% and 19%, respectively. For the concentrations of 17.50 g/L and 20.00 g/L there was an increase in temperature of 12.5% and 24.5% respectively, especially when the current reached values above 10 A, both compared to that of 10 g/L KOH. This behavior translates into energy losses, since the energy directed to the generation of electrolysis gas was used to increase the temperature in the electrolytic cell. The voltage for the concentrations of 12.50 g, 15.0 g, 17.50 and 20.00 g KOH was 12.9 V, whereas at the concentration of 10.00 g KOH there was an increase of 12%.

Finally, the reduction of the diesel consumption, using the gas from the electrolysis process as an additive, was of 2.40% and 3.25% for the concentrations of 17.5 and 20.0 g/L of KOH, respectively.

## 6. ACKNOWLEDGEMENTS

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