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Development and Characterization of an Ecological Hydrogen Stove

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Abstract: *In this work we developed and evaluated an ecological stove for food cooking, using hydrogen as the fuel. The operation of the device consists mainly of a renewable energy source, such as a photovoltaic system, which produces the electricity needed to power a bipolar alkaline electrolyzer from 1 kW to 1.9 kW, consisting of 85 stainless steel electrodes, which generates hydrogen for combustion in the cooking system. The prototype evaluation consisted of two main stages. In the first phase the operating parameters of the electrolyzer were obtained, achieving an efficiency of 60 to 77%, gas production from 3 to 6 L / min, with a maximum operating time of 395 minutes. The second phase focused on the cooking system, where the thermal efficiency of the device was determined, as 61.5%.*

Keywords: Ecological stove, Food cooking, Hydrogen, Hydrogen stove.

1. INTRODUCTION

The progress of the society and the acquisition of energy are widely related, with fossil fuels being the most used, bringing with it various problems, among which are the environmental pollution and the social problems. That is why it is of vital importance the research and development of alternative technologies, which can provide energy while preserving the environment.

In the less developed countries the use of solid biomass (firewood) plays a very important role mainly in rural areas, where it is used as fuel for cooking food, using open stoves, with energy efficiency between 8% and 10% [1]. In addition to the environmental problems caused by the use of firewood, there are social problems of gender, as women and children are responsible for the activity of acquiring biomass [2]. This action is possible by systems using renewable energies, based on biogas or hydrogen. In the first case, the advantage is a relatively simple and economic generation process, the disadvantage is the low calorific value of 17.31 J / kg of the fuel [3,4]. In contrast, the calorific value of hydrogen is 120.05 MJ / kg [5]. This is the reason why hydrogen is impacting as an energy vector, aimed at various purposes, whether for internal combustion engines or heat generation for cooking food [6]. Hydrogen catalysis stoves have achieved efficiencies of up to 80%, being superior to commercial electric stoves that have an efficiency of 35% [7].

The main objective of this work was to develop a pilot device for the production and combustion of hydrogen for cooking food and analyzing the energy efficiency of the device. The operation of the equipment is based on a photovoltaic system, where electricity is produced to feed an alkaline bipolar electrolyzer, through the current flow (CD) divides the water molecule into its main components (hydrogen and oxygen), then gases are led to the system of safety and purification to be burned in specialized burners. The study was divided into three main stages, the design of the devices, the construction of each of them and the evaluation, in order to obtain the efficiency of the system.

Hydrogen generation was performed by electrolysis of water by developing an electrochemical cell with alternative materials, in this case stainless steel as electrodes [8], the combustion system (burners) was specially designed for hydrogen, contemplating the reaction rate of the gas. The evaluation was focused on the electrolyzer and the cooking system, obtaining the efficiency of the device.

2. EXPERIMENTAL

The development of the ecological hydrogen stove was divided

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into several phases; each of them is presented below.

2.1. Configuration and construction of the stove

The development of the pilot device focused mainly on the hydrogen generator (electrolyzer), the cooking and support structure and the electronic and safety subsystems as presented in Fig. 1, trying to establish the design in an ergonomic and easy operation for users.

A bipolar alkaline electrolyzer (Fig. 1, part 2) allowed the generation of hydrogen for the present study. This electrochemical cell was constructed of stainless steel and alternative materials, with the possibility of working in 5 different levels of electrodes (from 60 to 85), with a total dimension of 46x30x30 cm, using potassium hydroxide electrolyte, stored in a container of Polyvinyl Chloride (Fig.1, part 1). The generated gas is transferred through conduits to a filtration system (Fig. 1, part 3) and then directed to the food cooking system, which consists of burners (Fig. 1, part 4). A control system controls the flow of gas, electrical consumption and activation of the equipment, thus ensuring the safety of the device (Fig. 1, part 5). All components of the system are integrated in a support structure (Fig. 1, part 6) made of stainless steel, with a volume of 0.88 m^3 divided into two sections by a wall of sheet. In the first zone were located the subsystems of production and purification of hydrogen (electrolyzer and filters) and the electrolyte container. In the second zone is where the cooking of food and the burners, valves, flame arrester and electric circuit measuring.

2.2. Evaluation

The evaluation of the device consisted of two main phases: the first one to study the electrolyzer, considering its electrical parameters of operation and the production of hydrogen, based on the procedure used by M.J. Lavorator [8. The experiments were performed at different molarities of potassium hydroxide (0.22 M, 0.11 M, 0.065 M, 0.045 M and 0.023 M) [6 by the following process.

1. Prepare the electrolyte at the corresponding molarity.
2. Add the electrolyte to the electrolyzer.
3. Perform temperature, voltage and current measurements using a digital multimeter. Measure the production every 10 minutes using the water displacement method or a flow bench. All this is done until a temperature of 60 ° C is reached in the electrochemical cell.
4. Allow the system to cool to room temperature.
5. Repeat the process for each level of the electrolyzer.

The efficiency of the electrolyzer was determined by equation 1 which considers the relation of the output energy and the input to the system:

$$EF = \frac{(E_{out})}{E_{in}} * 100 \quad (1)$$

where: EF = efficiency of the electrolyzer (%), E_{out} = electrolyzer output power (MJ), E_{in} = total input power to the electrolyzer (MJ).

The input power to the device (E_{in}) is determined by the electrical characteristics of the cell, contemplating the electrical power by the time of operation. The output power (E_{out}) is calculated using the amount of hydrogen generated by the calorific value of the gas.

The second phase focused on the evaluation of the cooking system. Having integrated all its components, it was used an adaptation of the methodology of evaluation of ecological stoves developed by O. Martínez [9].

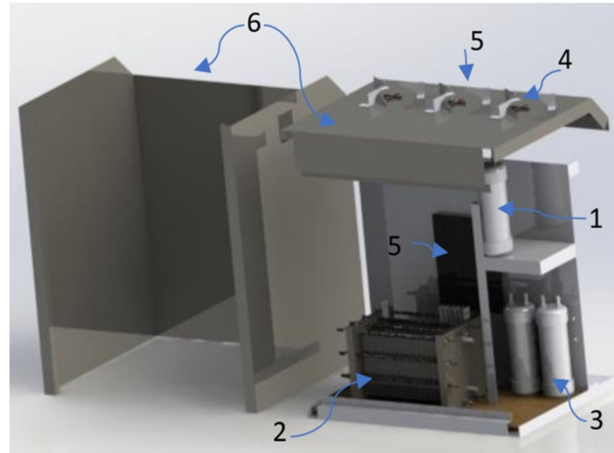

Figure 1. The general outline of the device design.

The experiment consisted mainly of increasing the temperature of one kilogram of water from 25 °C to 97 °C by monitoring various parameters such as temperature, water quantity, boiling time and quantity of fuel consumed. This allowed to obtain the initial characteristics of the performance of the prototype in a controlled environment and to ensure that the developed stove fulfilled the necessary requirements. This procedure was carried out in a comparative way between the hydrogen stove developed in this study and an electric grid of 1500 W.

The thermal efficiency of the two devices evaluated was obtained by the ratio of the useful energy given by the device and the total input energy expressed in equation 2 [10]:

$$Ef_t = \frac{E_0}{E_e} * 100 \quad (2)$$

where: Ef_t = thermal efficiency (%), E_0 = useful energy granted (MJ), E_e = total input energy (MJ).

The useful energy granted (E_0) is determined by the heat capacity of water ($4.18x10^{-3}$ MJ/Kg°C), temperature increase (°C) and the mass of the water brought to the boiling point (Kg) plus the mass of the evaporated water (Kg) divided by the latent heat of water (2.257 MJ/Kg). While the total input energy (E_e) is calculated by multiplying the calorific value of the fuel (MJ / kg) by the mass of the fuel used (kg).

3. RESULTS

The hydrogen ecological stove was developed and evaluated by the method described above; the device obtained is shown in figure 2.

The current consumed with respect to the number of electrodes is presented in figure 3. The decrease in the number of working electrodes increases the current consumption, obtaining a maximum current of 12.6 Amperes, for 70 electrodes. Likewise, increasing the number of electrodes leads to a lower current demand, with a minimum of 2.8 Amps for 75 electrodes. The current density ob-

Figure 2. The ecological hydrogen stove.

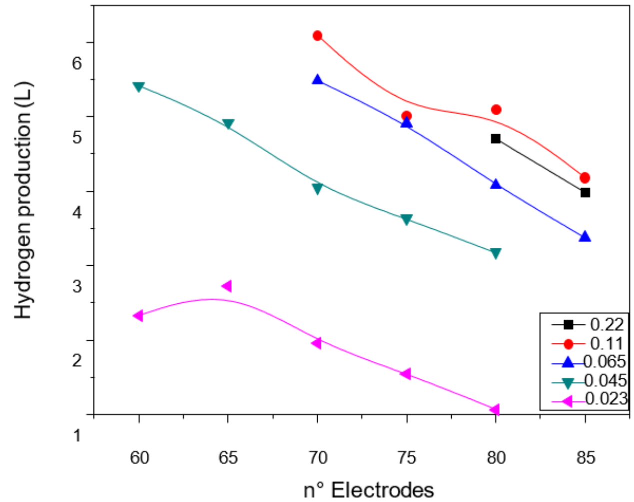

Figure 4. Hydrogen produced vs number of electrodes.

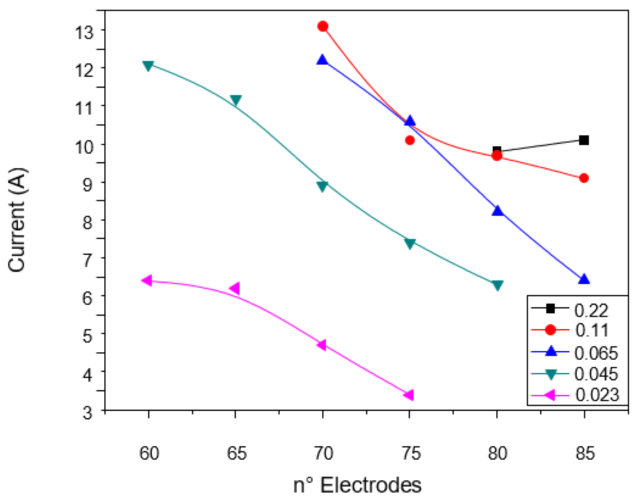

Figure 3. Current consumed vs number of electrodes, at different molarities.

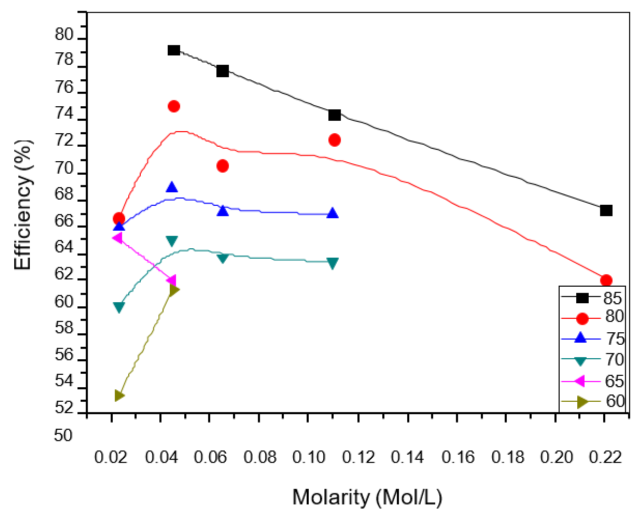

Figure 5. Efficiency vs Molarity.

tained by the electrolyzer was 238.18 A / m^2, at the molarity of 0.11 M. This result is close to the reported operating range for industrial electrolyzers [11].

Figure 4 shows the hydrogen production graph with respect to the number of electrodes, with the hydrogen generation being higher at lower number of electrodes, it is important to note that this behavior occurs independently of the electrolyte concentration. In the case of 70 electrodes the maximum production of hydrogen and the maximum current consumption of 6 L / min and 12.6 Amperes respectively were obtained according to the first law of Faraday [5].

By means of equation 1, the efficiency of the electrolyzer was determined and as can be observed in figure 5. There is a maximum efficiency peak when the electrolyte is at a molarity of 0.045 M, regardless of the number of electrodes. This is due to the fact that as the molarity of the electrolyte increases, there is a greater energy consumption caused by the generation of heat that occurs in the process. For the molarities of 0.045 M and 0.065 M, the electrolyzer had efficiencies between 60 and 77%, decreasing according to the number of electrodes, coinciding with that established by other authors [11], where it is mentioned that efficiencies greater than 50% are considered good.

From the evaluation of the electrolyzer, the optimal working parameters were obtained, efficiency was established between 1 - 1.9 kW at a molarity of 0.045 M.

In the water boiling test carried out in the two technologies mentioned above, it was obtained that the electric grill requires a longer operating time to carry out the boiling process (24 minutes), compared to 19 minutes of the hydrogen stove, with a decrease in time of 20.8% (see figure 6).

Another relevant parameter of the cooking systems is the thermal efficiency. According to the Federal Consumer Office (PROFECO) [12 it has been established that a commercial electric grill has a thermal efficiency of 30 to 60%.

According to the experiments carried out on the two technologies following the methodology proposed, it was obtained that the ther-

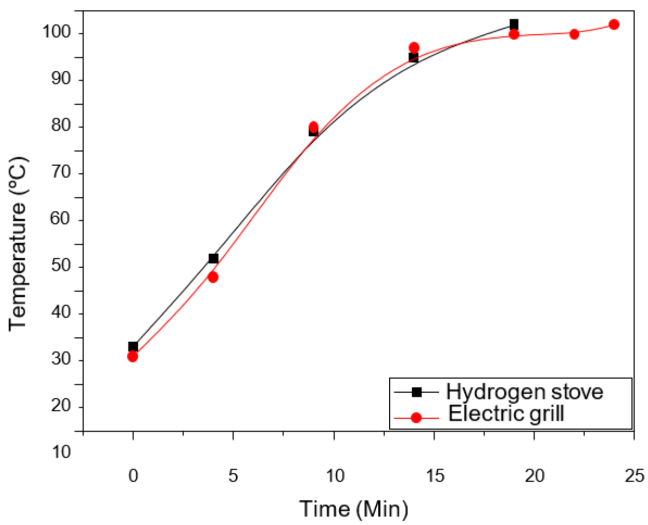

Figure 6. Temperature increase vs Operating time.

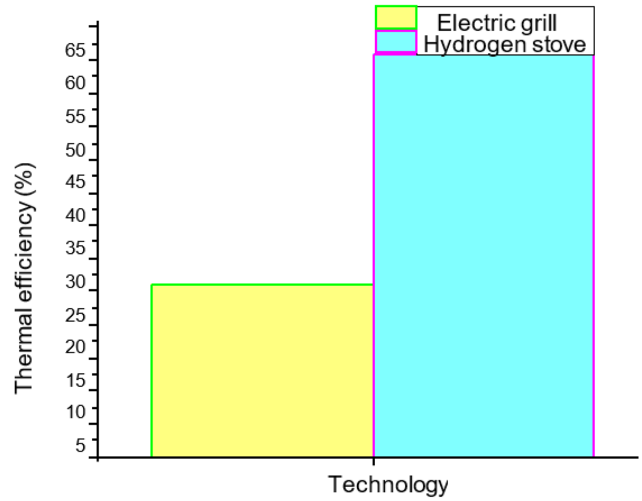

Figure 7. Thermal efficiency of hydrogen stove cooking vs Technologies evaluated.

mal efficiency of the electric grill is 28% while the developed hydrogen stove has a thermal efficiency of 61.5% (see figure 7). The latter having a 33% advantage over the evaluated electric grid, still being inferior to the hydrogen catalysis stove having a reported efficiency of 80% [7].

4. CONCLUSION

This research developed a pilot device for the production and combustion of hydrogen for cooking food, with the particular characteristic of generating its own fuel within the technology. The necessary safety equipment and adequate dimensions that allow an ergonomic and reliable operation was also developed. On the other hand, the developed device has higher efficiencies than the electrical stove technologies evaluated in this work. The electrolyzer used for hydrogen production and the hydrogen stove for cooking food were developed and characterized.

5. ACKNOWLEDGMENTS

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