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Wind Power For Hydrogen Production Using A Spiral Electrolyzer

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Abstract

The aim of this project is to use the electrical energy generated from wind to produce hydrogen by means of electrolysis process. The hydrogen is an energy carrier currently regarded as the energy of the future because of its great environmental advantages. An electrolyzer and wind turbine were built to evaluate the energy potential generated from wind for hydrogen production. Amperage consumption in electrolysis increases with increasing of electrolyte concentration; while, the voltage of wind turbine increases with increasing the wind speed. These voltages to allow the process of water electrolysis, due to voltages obtained from wind turbine are higher than thermo-neutral voltage.

Keywords: Renewable energy, wind energy, wind turbine, hydrogen, electrolysis, electrolyzer.

Introduction

The high global population growth and the disproportionate consumption of energy, forces society to find better energy sources [1], to replace conventional fuels. Thus arises the need for alternative renewable energies sources like wind, which can be harnessed to provide clean energy through of an electrolyzer for hydrogen production [2-5]. The hydrogen cycle does not pollute in any way, is absolutely friendly and harmonious with nature and human life [6]. Hydrogen is a secondary carrier of energy that, unlike electricity, once separated from composed molecules, can be stored to return its stored chemical energy back into electrical energy by means of a fuel cell. There are several emerging technologies for hydrogen production, mainly based on renewable sources, such as wind and solar energy.

Hydrogen used in vehicles, with fuel cell technology, represents a promising future for the hydrogen economy that mitigates climate change. However, there are challenges to be solved before its intensive use, such as, the cost of the fuel cell and hydrogen production that is energetically efficient. Therefore, the hydrogen production using wind energy becomes a pathway that contributes directly to the reduction of greenhouse gases that would help face the climate change [7, 8]. Recently an investigation was conducted in China, which clearly showed the necessity implementing hydrogen in automobile engines for the development of these vehicles industry [9]. Recent studies claim that gasoline blends with hydrogen increase the engine thermal efficiency and reduce CO_2 emissions [10]. The objective of this project is to design and built an electrolyzer-wind turbine to generate hydrogen by mean of electrolysis.

Experimental Procedures

This research project addresses the design and implementation of a system that reduces the fuel consumption (gasoline), in internal combustion engines. This device will operate with the basic principles of electrochemistry (electrolysis), where the energy source is produced by the wind to obtain hydrogen. To do this research is necessary to carry out a series of organized steps as indicated below.

Design of The Equipments

Analyze different power requirements for the proper design of the wind turbine, taking into account the physical configuration of the electrolyzer, which will be designed in a spiral shape.

Experimental Design and Equipment Implementation

The effect of the amperage and voltage on behavior for hydrogen production will be studied. First this will achieve by connecting between the electrolyzer designed and regulatory power source. It was analysed the voltage range of 0-16 V and current range of 0-3A. Then, it was performed the connection between the wind turbine and electrolyzer equipment to analyze the efficiency of hydrogen fuel production through wind power. Other variables taking into account are polarity settings on the electrodes, cell temperature and electrolyte concentration (KOH).

Design and Construction of An Electrolyzer With Spiral Shape

The electrolyser was designed taken 298 K as reference temperature and 308 K as working temperature (*T*). In addition, the reversible work was calculated using equation 1, where the number of electrons transferred in the water electrolysis is 2 and *F* is the Faraday constant equals to 96485.33 c/mol.

$$U_{rev} = \frac{\Delta G_r}{2*F} \quad (1)$$

If the process is not reversible, the done electrical work required for electrolysis is now:

$$U_{tn} = \frac{\Delta H_r}{2*F} \quad (2)$$

where U_{tn} is the thermo-neutral voltage, minimum voltage to assures water electrolysis.

For calculation of enthalpies (ΔH_r) at reference and work temperature was used the equation 3 and data given in Table 1.

$$H(T) = a_j T + \frac{4}{5} b_j T^{5/4} + \frac{2}{3} c_j T^{3/2} + \frac{4}{7} d_j T^{7/4} \quad (3)$$

Table 1: Values of coefficients for calculating enthalpies and entropies

Values of the coefficients of equations 3 and 4				
Molecule	a_j	b_j	c_j	d_j
Water	180	-85,4	15,6	-0,858
Hydrogen	79,5	-26,3	4,23	-0,197
Oxygen	10,3	5,4	-0,18	0

For calculation of entropy at reference and work temperature was used the following equation:

$$S(T,P) = a_j lnT + 4b_j T^{1/4} + 2c_j T^{1/2} + \frac{4}{3} d_j T^{3/4} - RlnP \quad (4)$$

With the values of the enthalpy is calculated the enthalpy change of the cell for each molecule in the reaction.

$$\Delta H_J = H_j(T) - H_j(T_{ref}) \quad (5)$$

Similarly, the entropy change is calculated by:

$$\Delta S_J = S_j(T) - S_j(T_{ref}) \quad (6)$$

Hydrogen flow rate in electrolyser is calculated with equation 7, and the length of each electrode of 2.88 m was calculated from the design data, such as amperage, efficiency, Ohm's law, and electric resistance. The electrodes were made in stainless steel and the container was built in acrylic (see Figure 1).

$$n_{H_2} = \eta_F \frac{NI}{zF} \quad (7)$$

Figure 1: Electrolyzer in spiral shape

Design and construction of the wind turbine

According to Betz's law, the power (P) that we could extract from the wind is defined as:

$$P = \frac{1}{2}\rho A v^3 c_p n \quad (8)$$

The rotor area is circular, if we replace $A = \pi\frac{D^2}{4}$ in the above equation, we obtain:

$$P = \frac{1}{2}\rho\pi\frac{D^2}{4}v^3 c_p n \quad (9)$$

Considering the values of 5V and 3A, to design the wind turbine. Furthermore, the wind turbine is located in Cartagena city, and Table 2 indicates the parameters of wind turbine. In addition, the rotational speed (N) of the wind turbine is defined by:

$$N = \frac{60\lambda V_D}{\pi D} \quad (10)$$

Table 2: Design data of the wind turbine

Parameter	Value
Power (P)	15 W
Diameter (D)	65.98 cm
Swing speed (V_D)	631 rpm

There are two configurations of the blades (Figures 2 and 3) that showed different efficiencies of energy produced. Configuration No.1 has ten blades and lower blade surface than blades of configuration No.2 with three blades.

Figure 2: Configuration No.1: ten blades

Figure 3: Configuration No.2: three blades

Results and Discussion

Variation of voltage and electrolysis concentration during electrolysis using a variable power source.

Water electrolysis was carried out to analyse the behaviour of the voltage and amperage in the production of the hydrogen. These experiments were performed at different concentrations of electrolyte (see Figure 4) and polarity of the electrodes in the electrolyser (see Figure 5); there recall that the hydrogen gas is produced at the cathode of the electrolyzer [11].

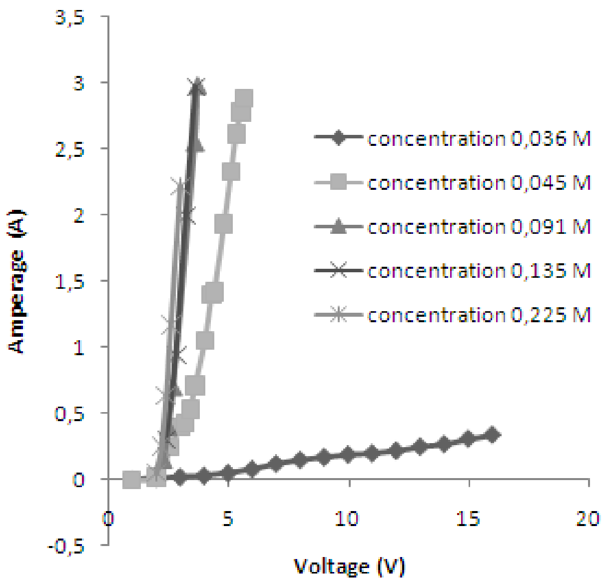

Figure 4: Effect of electrolyte concentration on the current and voltage of electrolyzer

Figure 4 shows that amperage increases with increasing of electrolyte concentration. In addition, the hydrogen generation increases with increasing of current, according to Faraday law. Similar behaviour was presented by [12]. In other hand, the polarity change of electrodes (see Figure 5), also, affects the amperage required by electrolyser. The amperage required by electrolyser with the inner cathode is higher than outer cathode.

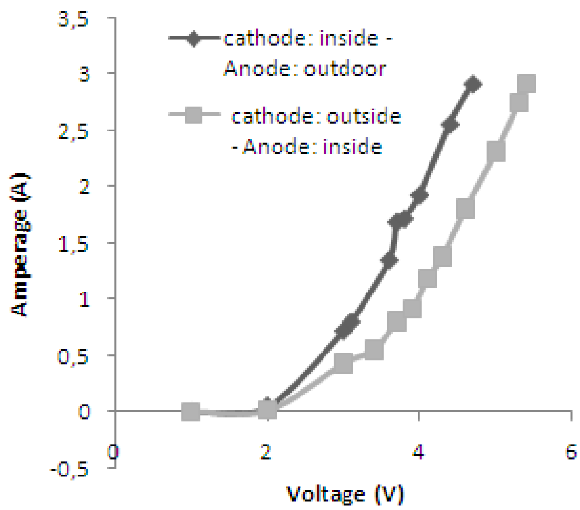

Figure 5: Effect of polarity change of electrodes on the amperage and voltage of electrolyzer

Energy Obtained From Wind Turbine At Different Wind Speed

Several experiments for each of the configurations of blades described above were carried out at three different wind speeds as indicated in Tables 3 and 4.

Table 3: Configuration No.1: ten blades

Wind speed (m/s)	Voltaje (V)
4.7	2.15
5.3	2.60
6.1	3.33

Table 4: Configuration No.2: three blades

Wind speed (m/s)	Voltaje (V)
4.7	4.12
5.3	5.10
6.1	6.10

As observed in both tables, the voltage increases with increasing the wind speed as observed in different investigations [Realpe Dyna y otras]. This result is in according with equation 8 where the turbine power is proportional to cube of wind speed. The turbine with configuration No.2 of blades generates higher energy than configuration No.1, due to highest blade surface of configuration No.2.

Energy From Wind Turbine Required By Electrolyzer

Finally, it was carried out the coupling between the wind turbine and electrolyser. The water electrolysis was performed at a concentration of 0.225 M of KOH. Blades with configuration No.2 was used due to highest energy generated.

Table 5 indicates the energy required by electrolyzer from wind turbine at different wind speed. As expected, the energy available from wind turbine for the electrolyser increases with increasing the wind speed. The water electrolysis was possible due to voltage obtained from wind turbine is higher to thermo-neutral voltage (1.48 v) required for electrolysis.

Table 5: Energy required by electrolyzer from wind turbine

Wind speed	Voltage	Amperage
4,7 m/s	2,12 V	0,11 A
5,3 m/s	2,18 V	0,20 A
6,1 m/s	2,22 V	0,31 A

Conclusions

In the present investigation was analyzed the possible use of wind energy as a source to produce hydrogen. This research was accomplished through a series of equipment designed and built, as electrolyzer, regulatory source and wind turbine. Voltage and current consumption of the electrolyzer increase with increasing the electrolyte concentration; however, electrical resistance decreases with increasing the electrolyte concentration.

The polarity changes in the electrodes affect the current consumption, which is reflected in the production of hydrogen, but these changes are not very significant. Furthermore, the configuration of the blades is an important factor to increase the energy of the wind turbine as occurred with configuration No. 2, which allow generate more hydrogen, due highest blade surface. The wind turbine generates power required by electrolyzer for water decomposition in hydrogen and oxygen. The results obtained suggest high potential of renewable energy to produce energy.

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