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Water Vapor Electrolysis By Using Electrical Plasma Method

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Abstract
In this study, electrolysis of water was carried out using high voltage electrical plasma method. In known methods, electrolysis of water is carried out by placing two electrodes in a certain volume of water and applying a low voltage but high current Direct Current (DC) electrical power. In this proposed method, a more efficient electrolysis process is carried out by adding water vapor to the environment in a certain volume and applying a high voltage but low current DC electrical power to the two electrodes placed in this environment. Since electrical power losses are proportional to the square of the current under normal conditions, electrical losses are higher at the high currents but low voltage at same power value according to the P=U*I relation. In this case, since the current is very high in the existing methods, the electrical losses are also very high. However, in the proposed method, electrolysis was carried out using the high voltage but low current application method at the same power value according to the P=U*I relation. Thus, since the current is very small, the electrical losses are also very low. In this way, the efficiency of the electrolysis process has been significantly increased.

Keywords: Electrolysis, plasma, energy, hydrogen production.

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1. Introduction

Due to the increase in energy consumption in recent years, some studies have been carried out to popularize the use of alternative energy sources. As a result of the researches, hydrogen production has been a significant solution to the increasing energy demand. For this reason, scientists agree that the problem will be solved by using the hydrogen energy system in all areas (1).

Obtaining hydrogen gas is called an energy carrier because it is one of the primary energy sources (2). If hydrogen will be used as an alternative energy instead of fossil fuels in the future; should be used as environmentally friendly and renewable energy (3). The most important advantage of using hydrogen as an energy carrier is that it has no effect on corrosion and hydrogen is a non-toxic element. The use of hydrogen is therefore safe and very simple, even with minimal precautions. Hydrogen, which is environmentally friendly, can enter into natural cycle reactions by producing water in recycling reactions (4).

Although hydrogen is more expensive than the use of other fuels, it is thought to play an important role in energy use with the technological developments in the future. The cost per kg is between $2.35-7 depending on the market need. However, since this cost is relative by researchers, rapid reduction rates are expected in the cost of hydrogen in the future (5).

1.1. Water Electrolysis

Today, natural gases used in the production of electrolytic hydrogen are considerably higher than the amount of hydrogen obtained by rearrangement of naphtha. The rearrangement of naphtha is preferred in works with high purity of hydrogen produced by this method. For example, it can be used in the production of nutrients and in the construction of semiconductor materials. Our need for hydrogen is increasing day by day and the increase in supply demand has led to the need to examine the cost of hydrogen. Researchers, on the other hand, are working on the cost of electrolyte hydrogen, so that water electrolysis systems can be fast and efficient, and they are trying to find cells with lower costs than existing methods for hydrogen production (6).

Generally, electrolytic hydrogen cells are produced by electrolysis of KOH or NaOH aqueous solutions. During the electrolysis of alkaline aqueous solutions, oxygen is obtained at the anode and hydrogen gas at the cathode and the resulting electrochemical reaction is shown in Equations 1 and 2 (7).

$$Anode: 4OH^- \rightarrow O_{2_{(g)}} + 2H_2O + 4e^- \qquad E_A = 0.401 - 0.0592 \quad pOH \quad (PO_2 = 1.0\ atm) \qquad (1)$$

$$Cathode: 4H_2O + 4e^- \rightarrow 4OH^- + 2H_{2_{(g)}} \qquad E_K = 0.828 - 0.0592 \quad pOH \quad (PH_2 = 1.0\ atm)$$

Total reaction;

$$2H_2O \rightarrow 4O_{2_{(g)}} + 2H_{2_{(g)}} \qquad E_{TR} = 1.23\ V \qquad (2)$$

Theoretically, E_{TR}, additional value from the inequalities was calculated as 1.229 V, the lowest voltage required for water to separate at room temperature (25 ^{o}C) (8).

1.2. Electrical Plasma

The electrical plasma method was first used by Siemens in the 1850s for ozone production, and it has been used in many and various fields in this field until today. It has been widely used in industrial areas especially in recent years. The application areas are getting more and more diversified day by day.

Under normal conditions, with the placement of two conductive electrodes in an insulating gas medium and the application of a voltage increasing with certain steps to these electrodes, this gas medium suddenly becomes conductive by undergoing an electrical puncture at any moment of the voltage. In this case, the gas medium becomes superconducting and a pulse-shaped and non-linear current flows through the circuit. The total charge per unit volume of the electrode gap (plasma medium) that becomes fully conductive is zero; In other words, it is neutral. In studies conducted in the literature, it has been stated that the electron-ion density per unit volume of the plasma medium is 10^{13}-10^{14} ion-electron/cm^3 (9).

There are many types of plasmas available in applications. However, in general, plasmas are divided into two main groups as hot plasmas (Arc plasmas) and Cold plasmas (Barrier, Corona, spark etc. plasmas). The thermal values of hot plasmas are around 10000-11000 ^{o}K on average. Cold plasmas are usually at room temperature or near. This provides significant advantages in terms of application. While the usage areas of hot plasmas are limited; the areas of use of cold plasmas are very common and very diverse because they do not leave any chemical destruction or residue in the areas where they are used. With these advantages, the usage areas are increasing day by day.

Cold plasmas are widely used in the chemical industry today. Many chemical reactions that cannot occur under normal conditions can easily take place in the cold plasma environment. On the other hand, the negative effects of cold plasmas on chemical compounds are negligible. This has a significant impact on the prevalence of use. In this study, the effect of electrical plasma on electrolysis, which is one of the electro-chemical processes, was investigated. With the scope of the study, unlike the existing applications, it is aimed to apply the high efficiency advantage of cold plasma to the electrolysis process of water (10).

2. Experimental

A specially designed reactor prototype was designed for the electrode system to be used in the experimental study. The type of material to be used in the design of this prototype is very important for the efficient operation of the reactor. As the electrode system, 2 planar electrodes cut in the dimensions of 100*50*2 mm, which have a smooth surface and were made of stainless steel, and can conduct electric current well, were used. In experimental applications, measurements were taken by applying plasma treatment in a closed reactor at different frequency and voltage values and constant steam flow.

5 mm thick fiberglass material was used for the reactor in the experimental system. Ultrasonic cold steam machine to give the desired amount of moisture to the closed reactor; adjustable voltage source to adjust the voltage at the desired level; In order to make gas measurements at the reactor outlet, a sensitive digital gas analyzer and an AC powered voltage transformer that can give the desired output voltage between 0-33 kV were used.

Hikoneb home-type brand and model steam machine was used to introduce cold water vapor into the reactor. The steam machine has a water capacity of 400 mL and the steam capacity is 0-5 mL min^{-1}.

The reactor system consists of 2 outer layers and 1 intermediate layer. Hard plastic made of fiberglass material was used for all 3 main layers. As can be seen from Figure 1, the dimensions of the outer layers were made of fiberglass material with dimensions of 10*5*1.25 cm and a thickness of 5 mm. On the other hand, material with the same measurement dimensions but with a thickness of 3 mm was used for the intermediate layer. Holes with a diameter of 5 mm were drilled in the intermediate layer to ensure permeability.

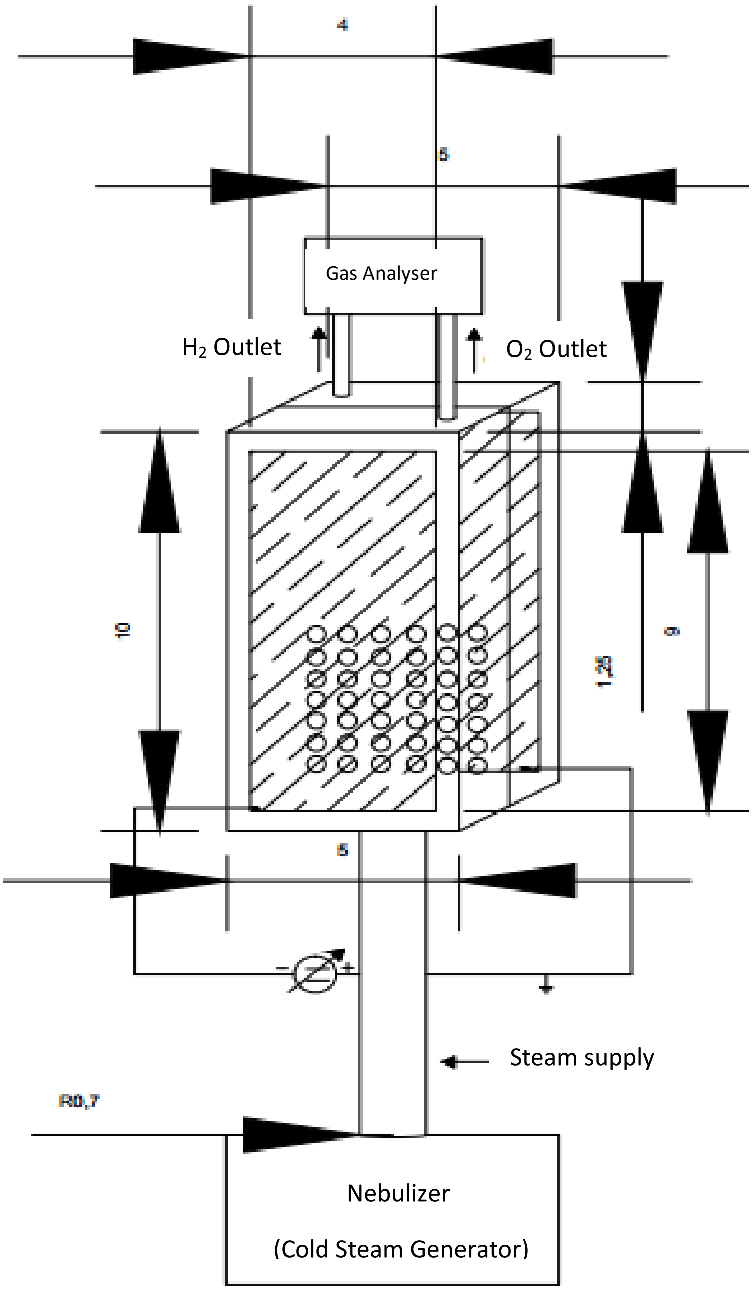

Figure 1: Technical drawing of the reactor used in experimental studies

In this study, unlike the current situation; according to the P=U*I relation, the method of having the high voltage value but the low current value was tried. Thus, the efficiency of the insulation parameter of the medium comes to the fore rather than the conductivity of the medium. Since the electrical plasma is capacitive, the higher the ambient resistance, the higher the efficiency is expected in terms of the efficiency of the plasma. For this reason, in order to perform the electrolysis process effectively, different from the existing applications, the applications were carried out by using the vapor phase of water instead of the liquid phase of water. In order to ensure that the resistance of the electrical plasma gap is large, no chemicals were added to the solution, and the experiments were carried out with the vapor phase of the spring water. In order to eliminate the effect of the temperature parameter, the applications were carried out in the form of cold steam and at room temperature with the help of an ultrasonic nebulizer.

Another important advantage of the electrolysis of water with the help of electrical plasma is that the products obtained in the plasma environment become an active ion or molecule and perform the action of forming various compounds. In this case, the produced O^- and H^+ ions enable to obtain various products by bonding with other elements (such as C, S, N) that are actively present in the environment with the effect of the plasma. This provides great advantages in terms of industrial production.

3. Results and Discussions

The net amounts of Hydrogen and Oxygen obtained in the electrolysis of water by electrical plasma method were determined by summing the amounts in the compositions of the products produced in the environment and the amounts produced directly. In addition to the direct production of hydrogen and oxygen in the plasma environment, the net amounts of oxygen and hydrogen numbers in various nitrogen and carbon compounds obtained from the environment were calculated and evaluated in the graphic environment. In the measurements and calculations, an average of 300 mL of water per hour was converted into cold steam by ultrasonic method. In order to prevent the temperature parameter from affecting the results, the applications were carried out at room temperature. In addition, since the current values are very small (in µA or mA levels) in plasma formation, electrical copper losses are negligible. Thus, there is no heating of the solution environment.

In general, the Voltage-Current characteristic in plasma assisted electrolysis is as in Fig. 2. Starting from zero, voltage and current change linearly according to OHM's Law as the voltage value increases. Voltage-Current values according to different frequency values are shown in the Fig. 2. It has been observed that at the same voltage values, more current is passed in the lower frequency value.

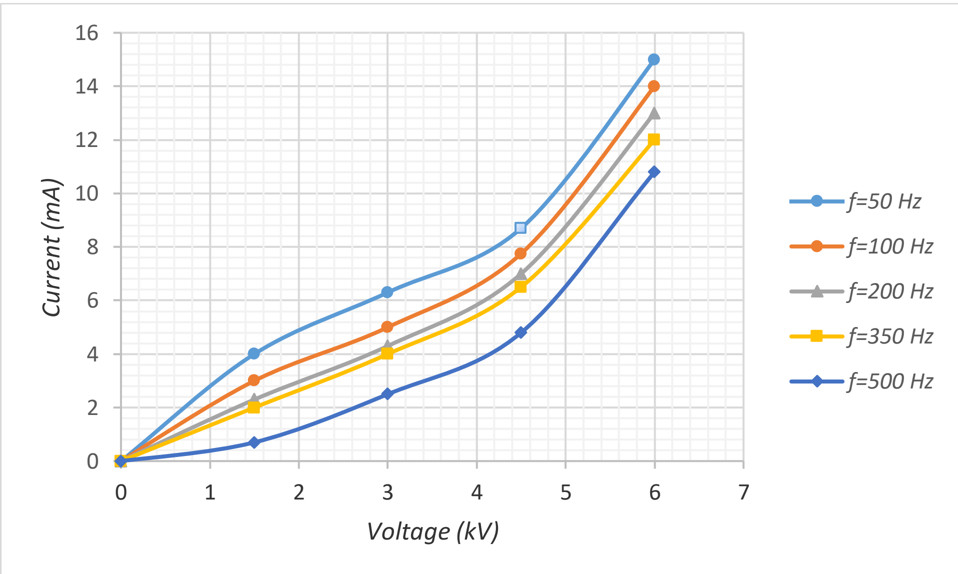

Figure 2. V-I characteristics of the generated plasma at various frequency values

In Fig. 3, the gas amounts formed due to the gradual increase in frequency at the constant value of the voltage (U=3 kV) are shown. The amount of gas formed at a frequency of f=100 Hz reached a maximum value, but as the frequency increased further, the amount of gas decreased and remained at a constant value because active plasma was formed in the environment.

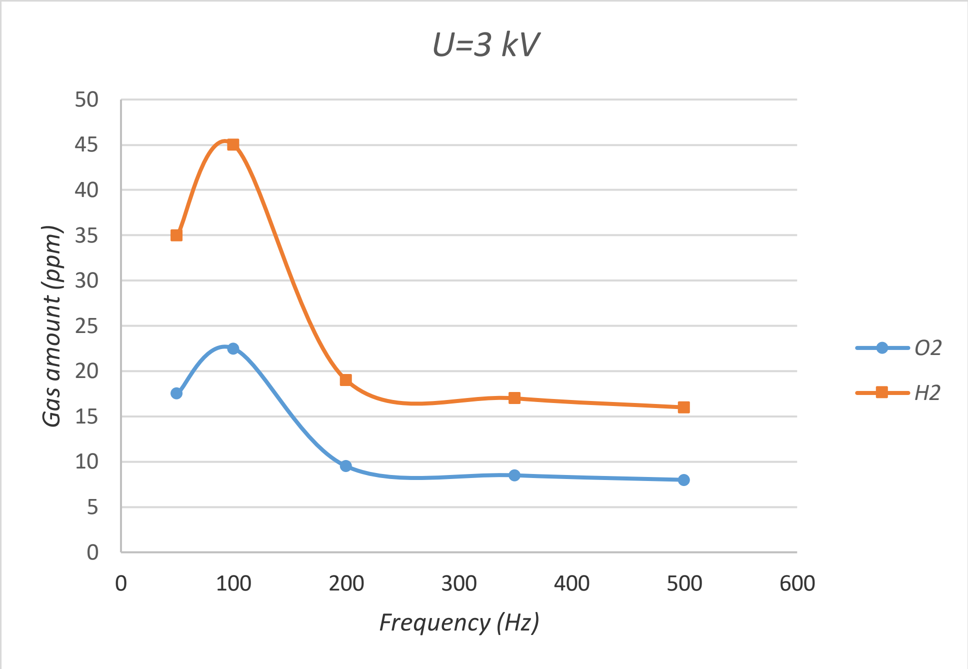

Figure 3. Frequency-Gas Quantity characteristic taken at constant voltage U=3 kV

Fig. 4 shows the Power-Time characteristics of the system at different frequency values. As can be seen from the figure, it has been observed that the amount of power consumed in the system decreases proportionally as the frequency value increases at the same time value.

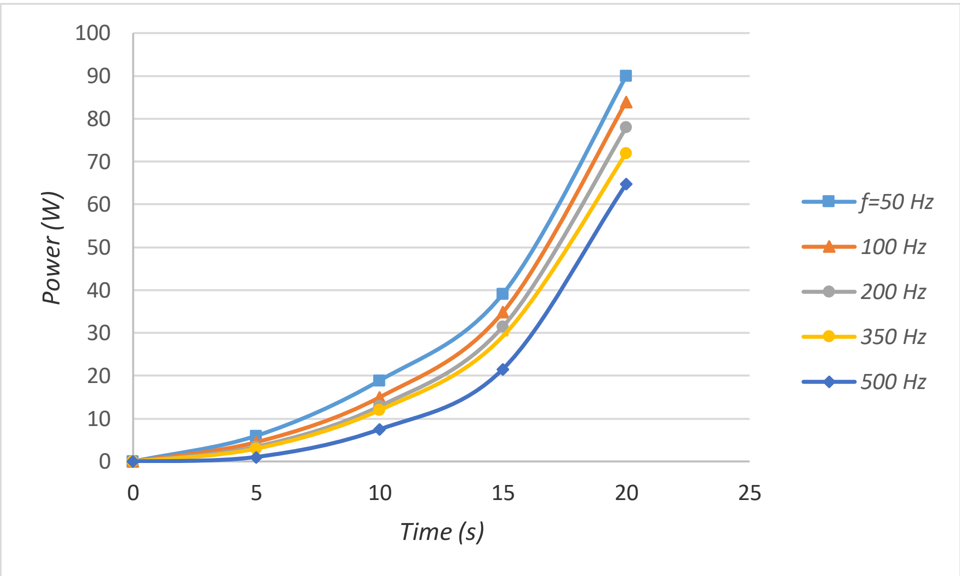

Figure 4. Power-Time characteristic of the system at various frequency values

Some special cases have also been encountered in the investigation of the effect of electrical plasma on the electrolysis of water. In the electrolysis process, besides the production of hydrogen gas and oxygen gas, ionic compounds of these gases were also obtained. This situation has an important feature from an industrial point of view. The formation of some nitrogen and acid compounds has also been observed as a result of the reaction of these gases, which are obtained in ionic form by the effect of electrical plasma, with the amounts of nitrogen or carbon in the environment. We think that some chemical compounds with high industrial value can be obtained by using such methods in the future.

4. Conclusions

By using the method proposed in this study, operations were carried out to break the bonds of water vapor molecules with the effect of forging or bombardment of the strong electric field in order to reduce electrical losses. In order to break the bonds of the molecules, the plasma environment was created by increasing the voltage to very high values, and the amounts of Hydrogen and Oxygen produced as a result of the bombardment of the charged particles in the environment were investigated. Since the losses are directly proportional to the square of the current and the plasma currents are at the level of microamperes or milliamperes, the amount of losses to occur has decreased to very low levels. In experimental applications, the amount of gas produced by the use of semi-direct current at various frequency values and electrical plasma formed at different voltage values was measured. It was observed that the rate of gas produced increased significantly with the increase in frequency, but a peak value was obtained in the amount of gas produced at a value between 100 Hz and 200 Hz. In the proposed method, since the plasma currents are at very low values (milliamps or microamperes), the copper losses in the system and the thermal losses in the environment are reduced to almost non-existent levels.

Since the gases produced in this method are activated by the effect of the strong electric field, they tend to form compounds with another ion. Therefore, it was concluded that plasma also has a side effect on electrolysis. For this reason, besides the gases produced, it has been observed that the formation of other by-products in the environment is possible.

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