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Design of a 20 m³/h capacity hydrogen generator by electrolysis and investigation of the effects of the porous electrode materials on parameters

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Abstract

Energy is one of the main factors which is determines their place in society the concept of a global world, in era we live in. In this context, communities are turning to renewable energy sources. Because, rezervs of fossil energy sources will be depleted in near future. The main purpose of this orientation, increase level of development using rich energy resources in terms of reserves without externally dependent. Reach unacceptable levels of environmental problems due to global warming is another requirement to accelerate the transition to renewable energy sources.

Hydrogen gas is most important potential energy carrier due to some properties which are human and adverse environmental any lack of effect, without limit, to produce and transport, energy content is high, multi-functional, effective cost of the properties.

In parallel with developing technology and science, quantity and yields of energy which is produce from hydrogen are increased when the energy expended to obtain hydrogen gradually decreased.

In this study; a unit produces hydrogen by electrolysis, which has 20 m^3/h capacity, was designed. First, the design parameters was determined. In the next step, an optimization method will be developed for detailed calculations. According to the data, unit will be designed in the real measure. Also, researches, which about the effects on parameters of the porous electrode material, were conducted.

Keywords: Electrode, Electrolysis, Hydrogen, Energy

1. Introduction

In world, almost all energies are used fossil sources. Reserves of fossil fuels are expected to run out in the near future. This situation, the necessity of the use of renewable resources as an alternative to fossil resources has revived and research have been initiated in many areas. To the secondary energies which are obtained by conversion of the primary energy source, also called an energy carrier. Hydrogen is the smallest atom which is chemical symbol "H" and the atomic number of 1 [1]. The hydrogen which is in the earth, found in the water molecules and fossil material. The pure hydrogen (H_2) is the artificial material, and only exists in trace amounts, such as 1 ppm in the earth's atmosphere. However, 75% of Jupiter, 90% of the toms in the universe are hydrogen [2]. Under normal temperature and pressure, hydrogen is a colorless, odorless, nontoxic gas and 14.4 times is a lighter than air [3]. Hydrogen has the highest energy density per unit mass [4]. Large portion of required energy is met from fosil sources. However, 40 years of world oil reserves, 67 years of natural gas reserves, coal reserves of 164 years, can not be given life [5]. Hydrogen is an energy carrier, It will mark the 21st century [6]. Hydrogen is not pure in nature. However, hydrogen can be generated from many sources of energy. The primary energy source which of fossil originated are among them. The

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most commonly used methods, steam-methane natural gas reform, partial oxidation of the oil, steam iron and coal gasification process [7]. However, they have limited reserve and and lead to the vast environmental damage. Therefore, hydrogen to produce water with clean energy source will be the best choice for our country which is covered with water at 3/4 percent and and in the production of hydrogen by electrolysis occurs any hazardous waste to the environment and human health. In addition, hydrogen production by electrolysis using electricity possible [8,9]. This situation is an important reason for electrolysis when considering the damage caused to national life by global warming.

The electrolysis is known as the simplest method for the production of hydrogen. When a direct current is applied to the electrolysis cell , hydrogen gas accumulates in the cathode and oxygen gas accumulates in the anode [10]. Electrolyte which in solution, may be acid or alkali [11]. There are three methods used in the electrolysis process: alkaline water electrolysis, solid polymer electrolysis and high-temperature steam electrolysis [12].

According to Faraday's law, 0,037 grams hydrogen gas and 0.298 grams oxygen gas occurs to per a hour and 1m3 hydrogen is needed to produce about 3.9 to 4.6 kW-hour of energy. For water electrolysis, at normal pressure and temperature, 1.23 volts is sufficient [13].

Hydrogen production by electrolysis has many parameters which affect the process efficiency. These parameters can be listed as electrode potential, pH of the medium, the electric field, temperature, activity of the electro catalyst, the use of porous electrodes, overvoltage and decomposition voltage.

After the production of hydrogen can be transported to the desired point or may be stored. Cost efficiency of a storage system is the most critical factor for the use of hydrogen gas [14]. Important storage techniques; as compressed gas storage, cariogenic (frozen) liquid storage, with the metal hydride storage system, the storage is carbon adsorption technique. Transport through pipelines, liquefied form transportation, road transportation, by sea transportation, air transportation can be considered in Methods of transport of hydrogen. In this study, an electrolysis unit which has $20m^3/h$ capacity will be designed. Mathematical calculations will be made on the parameters for designed generator to work with a maximum data. Acquisition of industrial-scale production technology of hydrogen gas with research will be acquisition of industrial-scale production of hydrogen gas technology with research will be great innovation about in gain of this energy.

2.Material and Method

Electrolysis is a process in which chemical compounds dissolve in redox reaction under the electrical current. This reaction comes from super elevation or degradation of the matter.

Electrolysis and hydrogen are used for improved production electrolytic which is used in different purposes and ways by many manufacturers and in this field there are a lot of R&D projects are being continued. In electrolysis pure water is being used. This is because of during the process there are some unwanted discontinuities and pure water can prevent these happening. For this purpose water which will be given to the system is filtered with special systems and this water is added to the electrolysis by this way life of electrolysis and hydrogen purification is improved.

By filtering hydrogen and oxygen which are coming out from the system and gathering them in a collecting chamber improves clean gas flow.

A crucial point for the system which might be used common ways is to be able to produce %100 dry hydrogen and to have a collecting chamber in which gases may condensate by touching its walls.

At this point gases which are produced by the system can be filtered and purified from the moist in them will have a positive effect on them. For this purpose creating a new drying system which will be used in commercial areas will be more economic.

Figure 1 shows a system which is created by considering all these points. To completely model a mathematical system which will be used for producing hydrogen with electrolysis, Faraday laws must be fully understood. M. Faraday whom was the first person viewing electrolysis event, presented two laws showing relation between the amount of current which is passing through electrolysis cell and the amount of matter separated from it. These laws are called Faraday laws.

According to these laws:

1- Amount of electrolytic decomposition products and the current which passes through electrolysis cells are in correct proportions.

2- The mass ratio which is separated from different electrolytes in a certain electric amount is equivalent to their chemical masses.

2.1. Mathematical Modeling

2.1.1. Electrolytic Solution

To produce hydrogen gas in electrolysis with water, usually KOH or NaOH solutions have been used because of pure water has less electrical conductivity. In balanced concentrations KOH solutions' conductivity is greater than NaOH solutions. Cell reactions are reaction which happens between a dissolved matter which was taken from outside or given electrical charges. These electrolytes must be highly purified and especially must not contain chloride.

Because chloride in electrolytes especially in anode creates a corrosive effect.

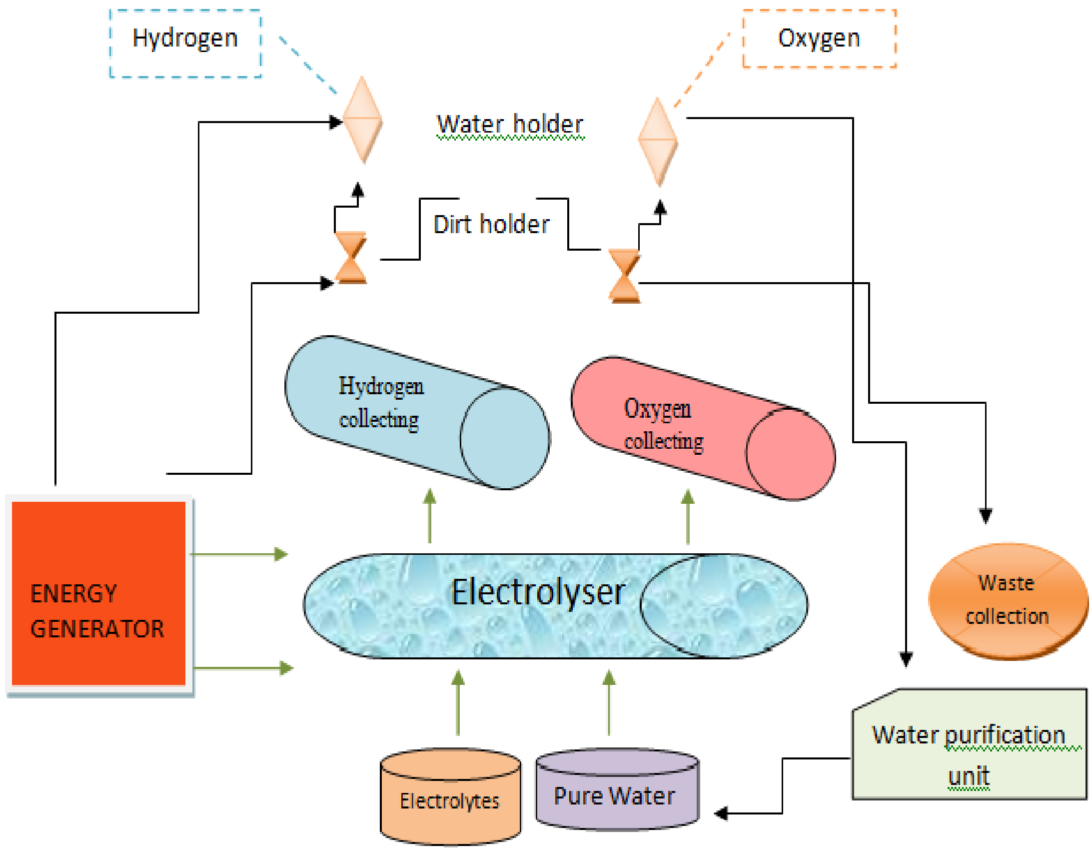

Figure 1. Schematic representation of the electrolysis unit.

Some gases (carbon dioxide etc.) which dissolve in electrolyte solution make electorate dirty and make its conductivity less. For this reason in electrolyte solutions these gasses absorption levels required to be less. KOH solution absorbs less amount of carbon dioxide than NaOH and because of this reason KOH solution preferred mostly. Electro chemical cell reactions of alkali waters electrolysis are shown as below.

Cathode: $4H_2O + 4e^- \rightleftharpoons 2H_2 + 4OH^-$ (2.1)

Anode: $4OH^- \rightleftharpoons 2H_2O + O_2 + 4e^-$ (2.2)

Electrolysis Reaction:

$2H_2O \rightleftharpoons 2H_2 + O_2$ (2.3)

In these reactions cell intensity is equal to sum of anode and cathode intensity

$$E°_{hücre} = E°_{katot} + E°_{anot} \quad (2.4)$$

The research which is made on electrolysis cells showed that it isn't always possible to reach in under the standard temperature and pressure for desired efficiency value. Because of these during the studies to prevent as little errors as possible there are some formulas and rules have been used. These are the ones which are created by German chemist Walther Hermann to be used in when there aren't standard conditions.

$$\Delta G = \Delta G° + RTlnQ \quad (2.5)$$

According to Gibbs laws if the gibbs free energy is written instead of reaction electrical energy the following equation can be derived.

$$n.F.\Delta E = n.F.\Delta E + RTlnQ \quad (2.6)$$

For one mol product which is derived under 25°C working temperature considered, the cell potential equation can be simplified as follows.

$$\Delta E = \Delta E° - 0.0592x\ln Q \quad (2.7)$$

$$\Delta E = \Delta E° - 0.0592x\log\frac{1}{[H]^+} \quad (2.8)$$

$$\Delta E = \Delta E° + 0.0592x\log(H^+) \quad (2.9)$$

The static values which belong to cathode functions will be used during calculations are as follows.

$$e_{H^+,H^2} = E^0 + 0,059.\log\ (H^+) \quad (2.10)$$

$$e_{K^+,K_0} = E^0 + 0,059.\log\ (H^+) \quad (2.11)$$

When the values are calculated if the equation is like e_{H}^{+}, $_{H2}$ > e_{K}^{+}, $_{K0}$ if the equation is like 2.10, e_{K}^{+}, $_{K0}$ > e_{H}^{+}, $_{H2}$ and if the equation is like 2.11 will happen.

The static values which belong to anode functions will be used during calculations are as follows.

$$e_{OH^-,OH} = E^0 + 0,059.\log\ (pH) \quad (2.12)$$

$$e_{K^+,K_0} = E^0 + 0,059.\log\ (pH) \quad (2.13)$$

2.1.2. Determination of Electrolysis Dimensions

Michael Faraday who explained the quantitative relation change between electrical and chemical, at the end of his research on electrolysis experiments he came up with a correct proportion equation that the sum of matter amount is equal to the current which passes through circuit.

$$m = \frac{Q}{F}\frac{M}{z} \quad (2.14)$$

In the equation 2.14'te instead of Q if we write Q: I.t we can get the equation which is matter produced is depended on time.

$$m = \frac{I.t.M}{F.z} \quad (2.15)$$

During the electrolysis if the potential is kept constant the changes in cell current can be observed. When the electrolysis passes the iodine in the solution will be lesser and with that so does the current, but concentration polarization will be higher. In reality when the concentration polarization starts current will be less over the period of time.

$$I_t = I_0 . e^{-kt} \quad (2.16)$$

In the equation 2.16 if we change k constant with $k = 28.5.\frac{D.A}{V.d}$ detailed current change will be found,

$$I_t = I_0 . e^{-\frac{28.5\ x\ D\ x\ A\ x\ t}{Vxd}} \quad (2.17)$$

In here D: diffusion multiplier, A: electrode surface area, V: Volume, d: surface plate's thickness.

2.2. Electrolyser

Hydrogen, widely used, more effective than any other gas and doesn't make any harmful absorption to environment is being used on electrolytic experimental systems showed that required efficiency has not been reached. That's why in this field of study to get required efficiency there will be two different types of electrolysis designs need to be used.

2.2.1. Design Criteria

- During the Electrolysis the amount of hydrogen to be produced will be equivalent to current's value, it will be depended on to electrode surface area. There must be minimum size of electrode to be used to get desired amount of capacity.

- During the hydrogen production it is important to have the distance between electrode surface area and electrodes it selves. This is why the distance between electrodes must be optimum level and from that there must be a design to be created.

- In the electrolysis giving energy to each electrode will make the system over tensed; to prevent this current passage must be done in overlapping shape.

- The hydrogen and oxygen which will be produced by the system will be used separately that is why electrolysis mut be placed with two different collecting tubes and chambers.

- DC current source must be used in system to have more easy usage all over the system.

2.2.2. *Design Process*

First design stage shows that to get the desired amount of capacity there must be an electrode which will have a minimum size of diameter. Hydrogen which will be produced by the system will increase exponentially depending on the amount of hydrogen in the current and the electrode surface area. In this case to get the desired amount of capacity electrode diameter needs to be increased however this isn't the only way, in other case electrodes with porosity can be used. With the pours on surface, surface area will be increased and more pours on surface will reduce the electrodes diameter size. This is why in the system there will be two types of electrodes used to decide the effect of porosity electrode on the amount of matter to be produced.

There were tests on the pours to decide which type of geometric form to draw on it, and in the end it has been decided that to there must be spherical type of pours to have resistance against to corrosion and to have surface sustainability.

Electrolysis was created with transparent polypropylene plastic material so that it will not be affected with voltage on which is on its outer surface. By this way system was easily observed even though measuring devices and collecting chambers were on high tensed.

In the studies there were different types of electrode materials have been used for to evaluate electrolysis effect.

In the design it has been decided that anode and cathode diameters are 57,03 cm and their thickness are 0,5 cm and they were placed on 485 electrodes which each of their surface area is 0.49 cm^2.

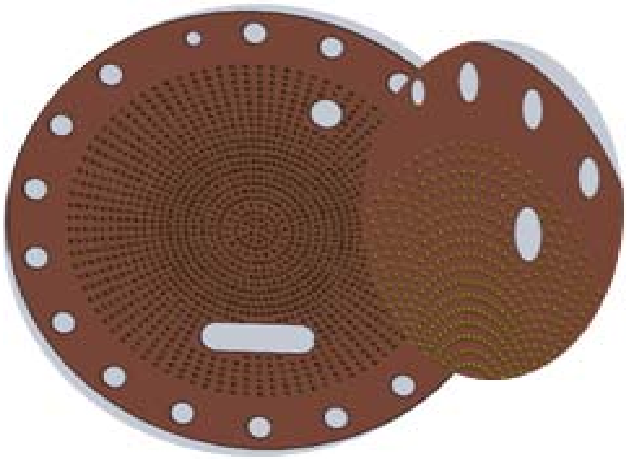

Figure 2. Designed electrode.

With placing a neutral electrode which isn't connected to current points behind to charged electrode, over tensing the system was prohibited. At the same time with using rubber gasket tightness is provided to system. In the Figure 2 designed electrodes is shown.

Electrolysis generator was completed with, anode and cathode groups of 212 plates, 2 end lids, 1 middle ring, 2 gas collectors and other support pieces.

As shown on the Figure 3 in design, in one single unit body was cut in half in the middle to collect the hydrogen and oxygen gasses at the same time and this area was left empty so that gas collecting ducts can go outside.

By this was a principle was created for to work on separated ways.

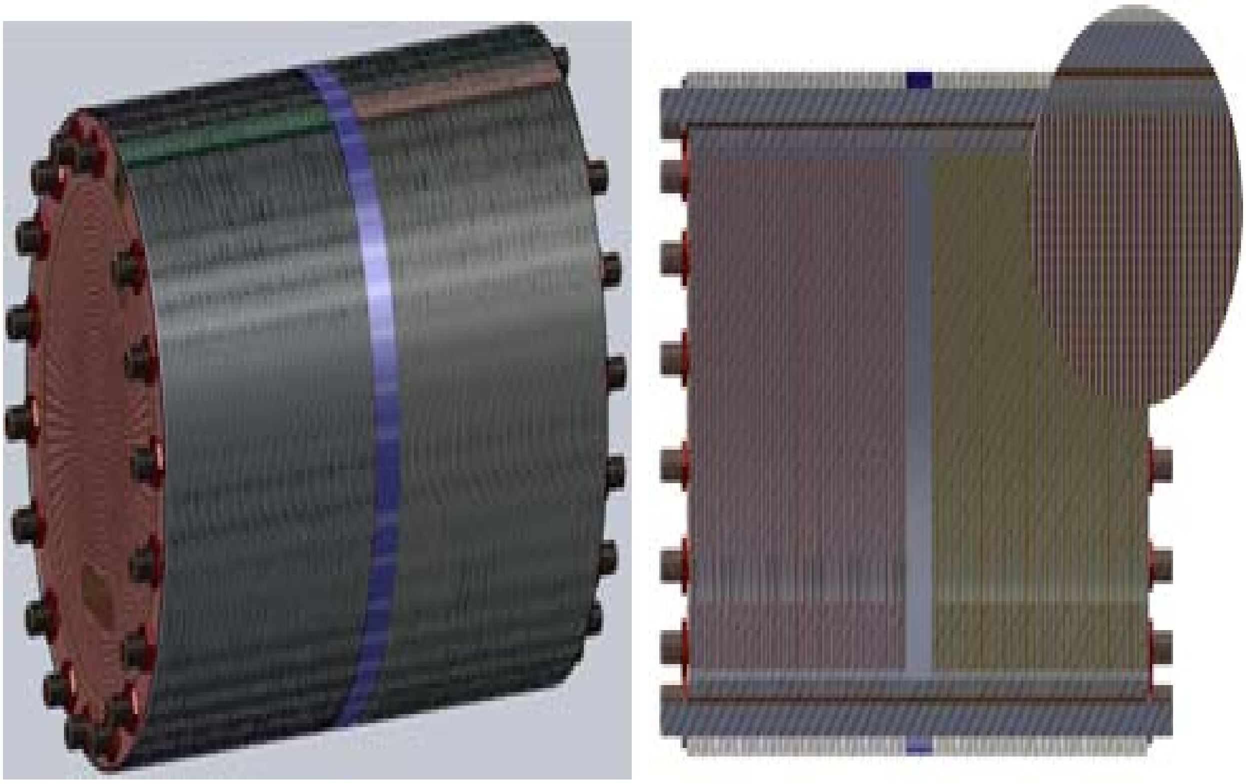

Figure 3. Designed electrolyser.

One on side of electrolysis there is a production of oxygen and on the other side production of hydrogen. By this way on one electrolysis unit there will be 2 different types of gas will be collected. To preliminary assessment the design of the system, the prototype electrolysis unit created with hard plastic and 30 x 60 x 20 cm measurements. Inner chamber has been divided on two from the longer surface for anode and cathode electrodes and each chamber was cut and placed with 40 pieces 6cm^2 diameter, AISI 316L electrodes. In this design planar electrodes were chosen not the ones with porous. Before beginning to study to prevent surface discontinuities on the electrodes, the electrodes were treated with mechanical shiner sand. In the Figure 4 shows the prototype electrolysis unit.

Collecting area which is on top of the chamber was divided in half to gather the oxygen and hydrogen gasses separately. There are two indicator chambers right next to collecting chambers for to check solution levels. Figure 6 shows prototype electrolysis unit and electrolysis chamber. Also in the system, voltage which is applied, current and temperature check indicators are placed.

In this manner as for anode electrode platinum and steel electrodes were chosen, as for cathode group it has been decided that there must be study to be done on different types. All the calculations assumed on 1M KOH solution. For the cathode electrodes which are going to be used in electrolysis to produce hydrogen, the following types of electrodes are

decided: quicksilver, steel, nickel, brazen and copper. These calculations were obtained from the standard electrode potentials. Depending on the electrode features, voltage which will be applied, electrode surface area, application time and solution volume calculates the amount of the hydrogen gas will be collected theoretically.

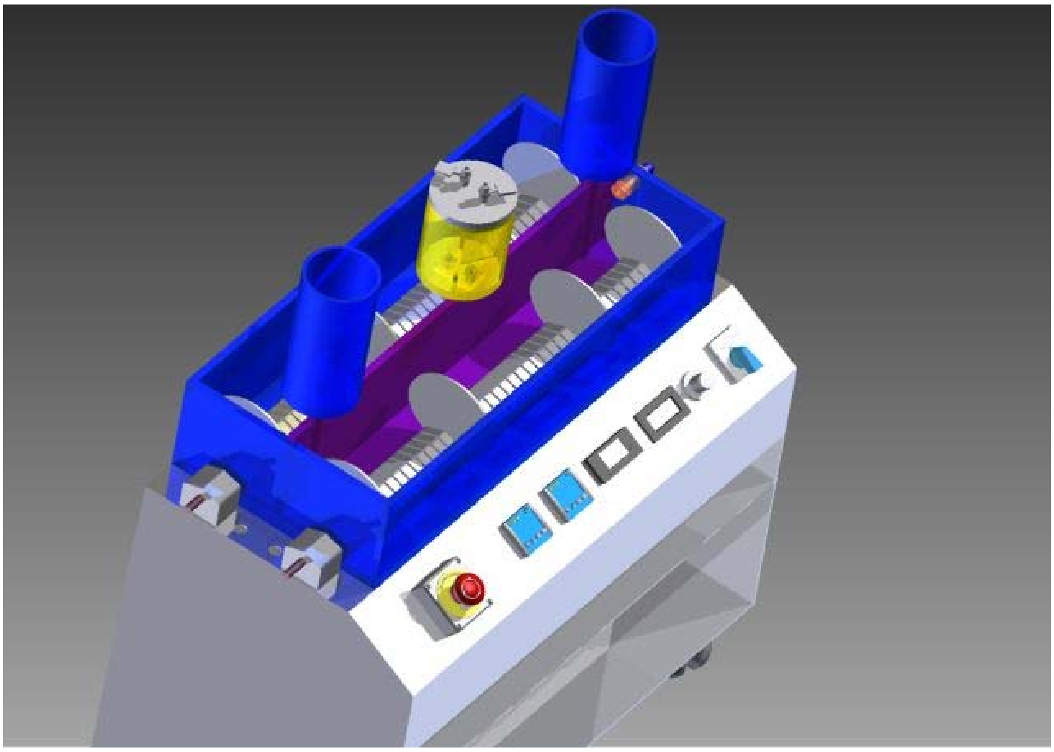

Figure 4. Prototype electrolysis unit.

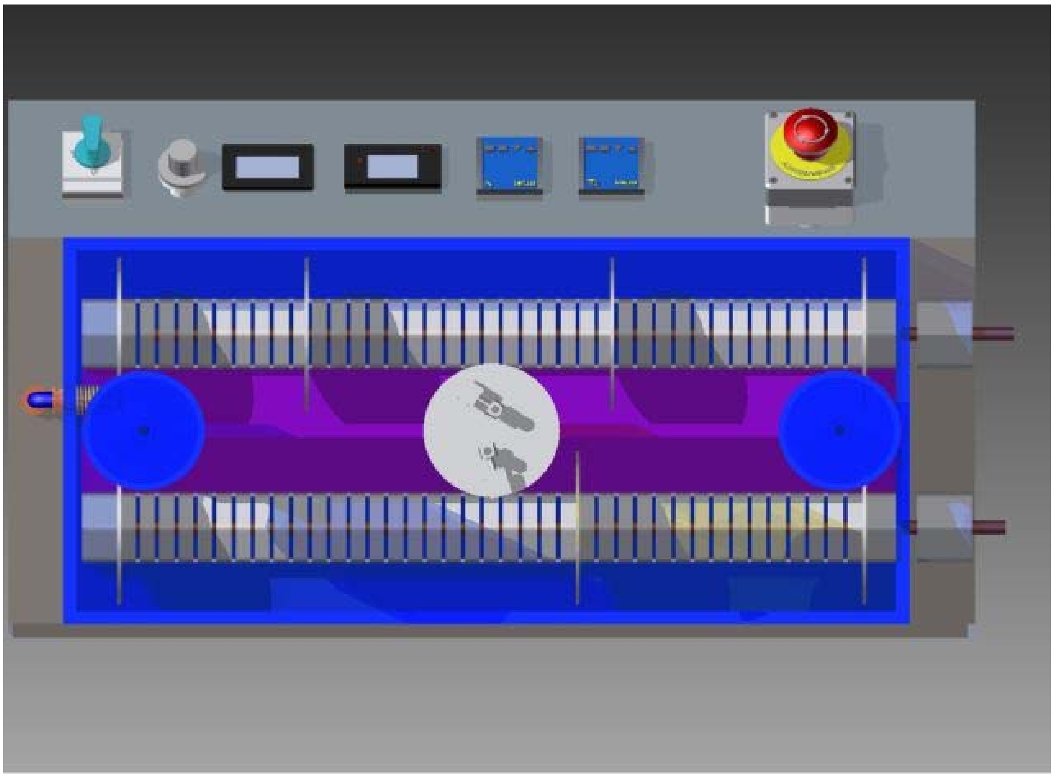

Figure 5. Prototype electrolysis

Table 1. Dissociation voltage for different electrode pairs

Model	Anode	Cathode	Decomposition Voltage
Model 1	Platinium	Quicksilver	1.64 Voltage
Model 2	Platinium	Steel	1.07 Voltage
Model 3	Platinium	Nickel	0.62 Voltage
Model 4	Platinium	Brass	1.69 Voltage
Model 5	Platinium	Steel	1.23 Voltage
Model 6	Steel	Steel	0.59 Voltage

Assuming electrolysis will work on pH = 10^{-7} in the calculations which are made on 2.10 and 2.11 equations $e_{H^+,H^2} = -0.41$ voltage and $e_{K^+,K_0} = -2.925$ volt calculated. Because of $e_{H^+,H2} > e_{K^+,K0}$ cathode voltage which will be used in design is set for $e_{katot} = -0.41 + e_{elektrot}$. In the calculations which are made on 2.12 and 2.13 equations are $e_{OH^-,OH} = 0.8$ voltage, $e_{Pt^+,Pt} = 0.41$ voltage evaluated as such. According to these calculations the result is $e_{anot} = 1.28$ voltage. With these standard values used for separation voltages calculated and are shown on Table 1. $V_0 = 100$ voltage, $I_0 = 569.948$ current, $t = 10$ min, $D = 0.22356$ cm, $A = 2215$ cm^2, $V = 100000$ cm^3 with startin values the equation 2.17 shows the current change in electrolysis solution depending on the time is Figure 6. By using Mathcad Prime 3.0 program $V_0 = 100$ voltage, $V = 100000$ cm^3, D = 0.22356 cm and A = 2000 cm^2 with starting data over the 60 minutes of period of time the distance between electrodes keeping constant and depending on the surface area, hydrogen which will be produced on the equation is calculated as 2.15 and 2.17. According to the data depending on the surface area amount of hydrogen will be produced is shown on Figure 7.

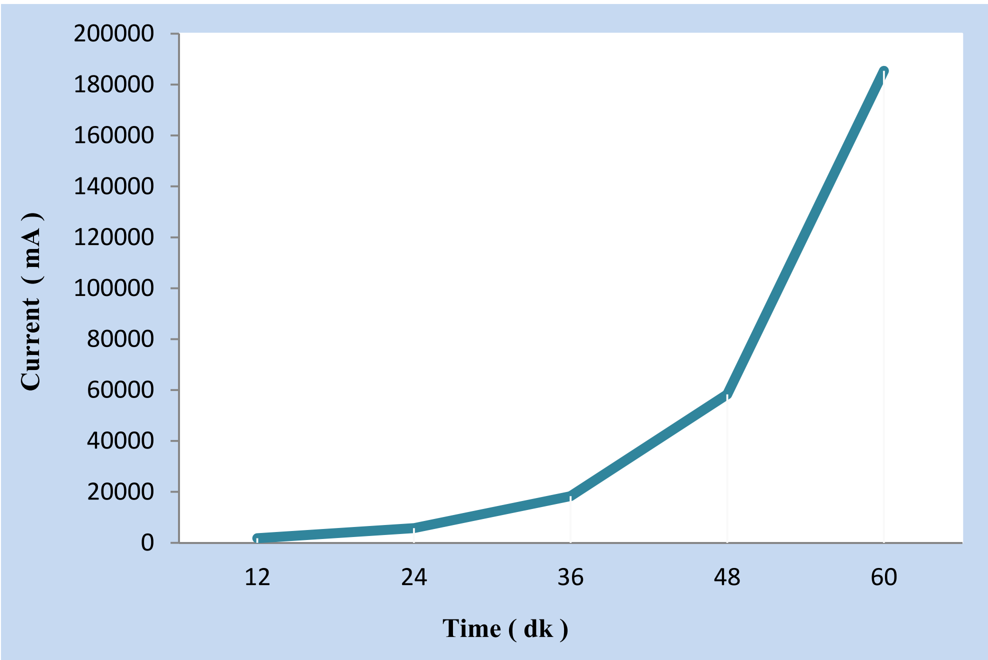

Figure 6.The figure shows the current change with time.

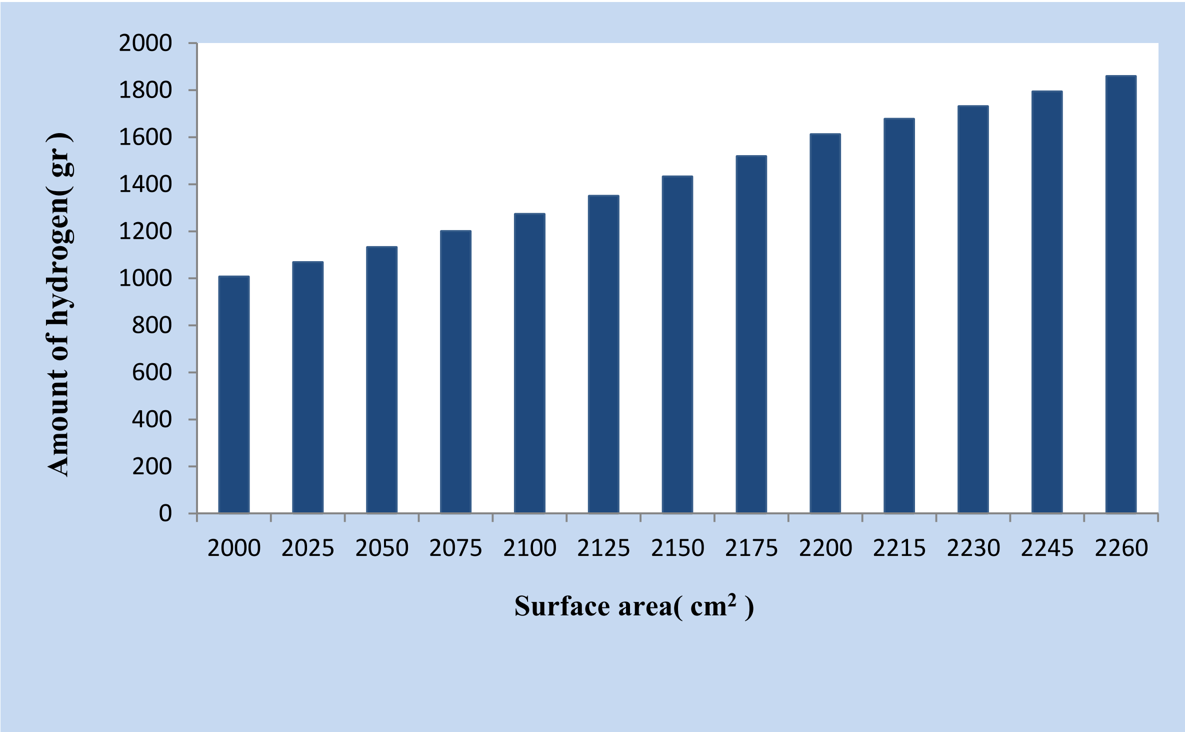

Figure 7. The amount of hydrogen generated due to the electrode surface area.

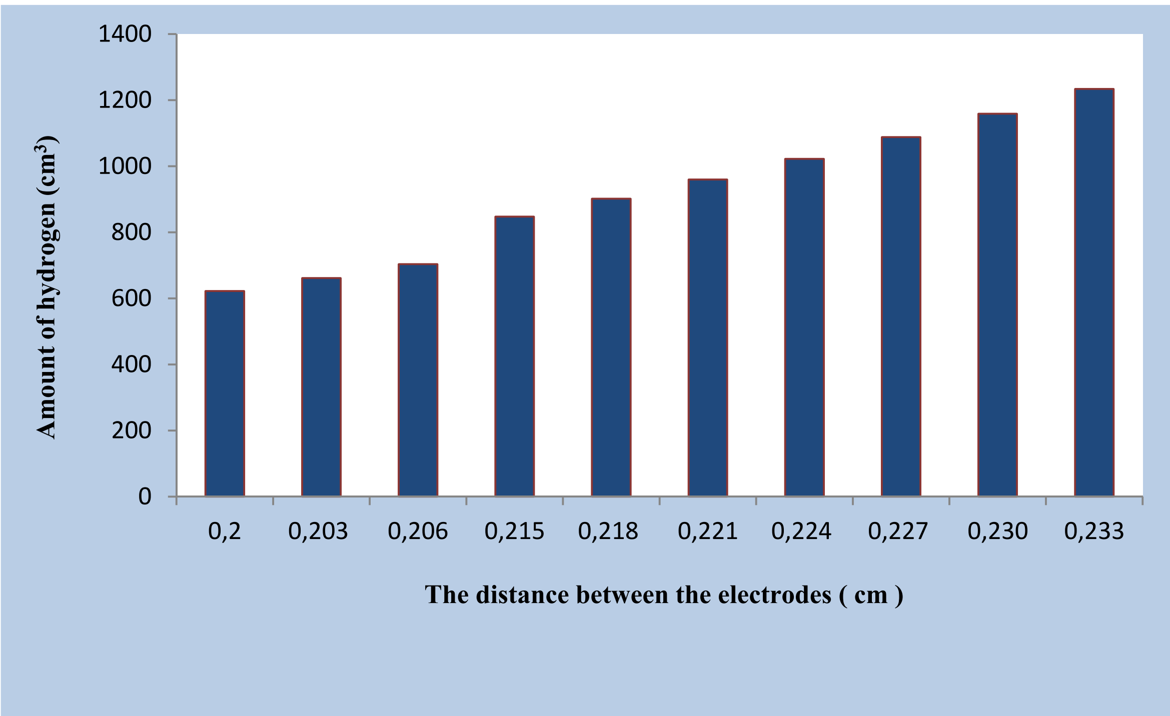

Figure 8.Distance between the electrodes connected to the current-potential curve

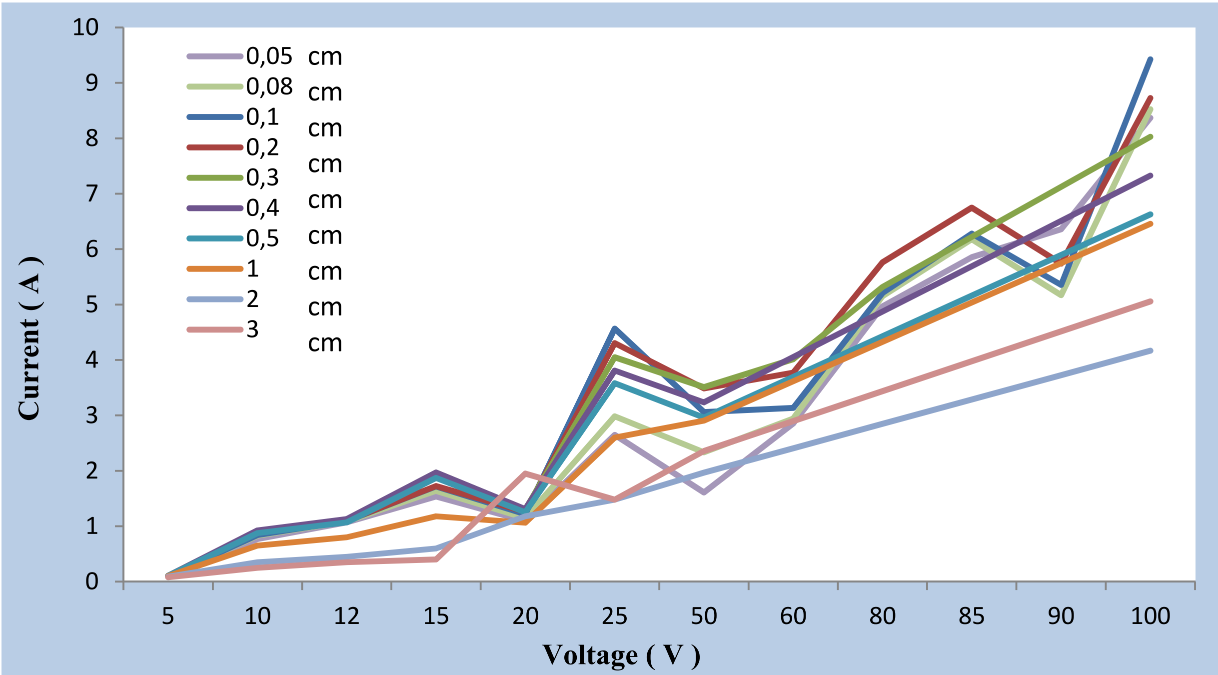

Figure 9.Distance between the electrodes connected to the current-potential curve.

At the same starting values electrode surface area (A = 2000 cm^2) is held constant hydrogen amount depending on the electrodes are shown on Figure 8.
To evaluate hydrogen production with electrolysis electrode surface area and the distance between electrodes, these two variables used in 15 different ways and the end result is shown on Illustration 3.4.
By using linear electrodes with the same starting values the result should be $A = 2050.84$ cm^2. In this case with the equations done in 2.15 and 2.17 in the end maximum electrode surface area was read 215 cm^2 per hour producing 20 m^3 hydrogen gas. This value shows the distances between electrodes are 0,223 cm.

Which means calculations done by using porous electrodes 1680 gr of hydrogen can be produced.
The amount of power is going to be applied on porous electrode used system is 56.994,8 watts. Considering 1 m^3 of hydrogen to be produced with this system and with the same features the amount of energy is going to be spent is 2.849,74 watts.

2.2. Experimental Results

2.2.1. Obtained 0.2 M KOH Solution ın the Current-Potential Curves

In the studies by using stainless electrodes in 0.2M KOH solution in open atmosphere conditions, the amount of current potential curves are shown on Figure 9. When we observe the curve, the amount of voltage is increasing exponentially with the current values. Until the 1cm distance space the current value is up to 15V and when it comes to 1cm it starts to drop. The same fall can be observed in 3 cm space and 20 V but when it comes to 2 cm this value will be higher. In experiments carried out (regardless of the distance between the electrodes) has been shown to increase the voltage of the system it is applied parallel to the current value. But the distance between the electrodes under constant tension increases the delivered current value has declined. The resulting graph evaluating the optimum electrode distance below 100 volts used in the computation was read as 0.1 cm.

2.2.2. The solution obtained due to the current-potential curves Concentration

The current potential curves in stable solution which develops by applying different voltage values are shown in Figure 10.

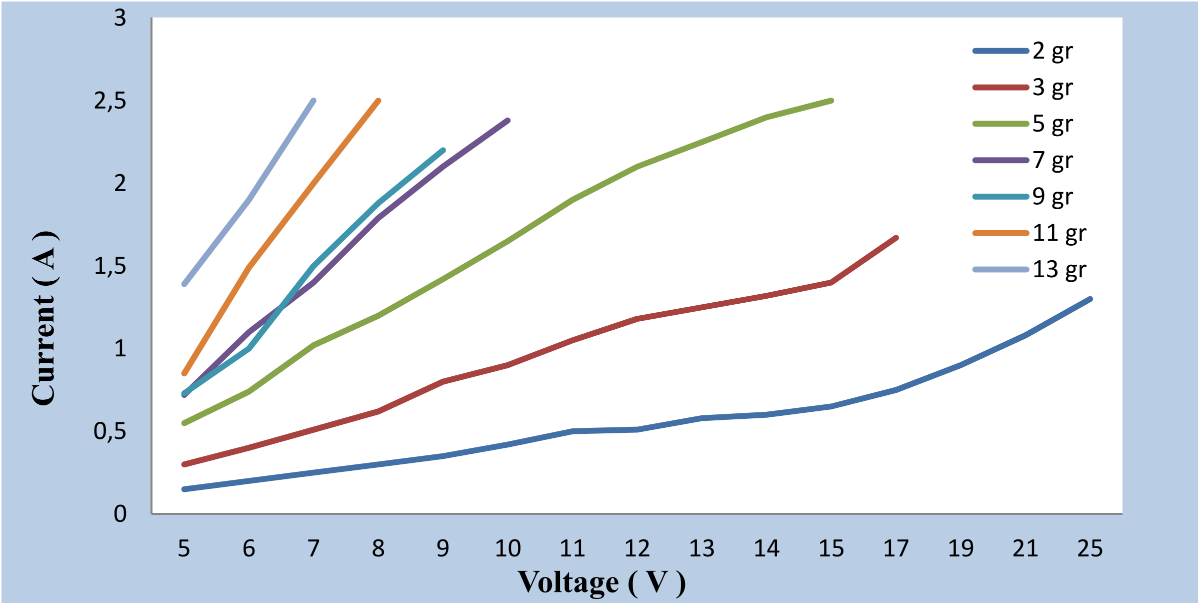

Figure 10. Concentration-dependent current-potential curve.

Concentration in studies to investigate the effects of electrolysis flow occurs, as observed in other analyzes, was found to be proportional to the applied voltage and current. The increasing concentration of the solution led to the formation of a higher current value.

3. Results

One of the clean sources of energy, hydrogen is now trying to be produced by natural sources usage but not in desired values was an inspiration to this study. In this thesis by using %100 clean natural pure water theses aimed to produce high system efficiency hydrogen production.

In theoretic calculation experiments it shows that in the constant tension applied to system, the current which passes through the system increases functionally. In this case some of the charge may stay in the system depending on the charge applied to system. Under the constant tension increase of the current which passes on the system, applying discontinuous tension to solution which will cause to system to have constant current value. If this is the case, in electrolysis embodiments it will be important to have always the same constant tension to the system.It has been observed that the current which passes through the system has a direct relation on currents solution concentration. In this case solution concentration kept constant under the saturation level will make the system have more efficient values. In the electrolysis systems, to have a faster hydrogen separation process and to have the lowest first applied tension, there must be an electrode which has the lowest separation tension. In Figure 7, such as steel and steel mapping will be your best choice.

During the assembly of designed electrolysis unit for each conductive plate there is a neutral plate placed between. With this the distance between electrodes increased and also over tension is prevented. In the electrolysis unit the distance between electrodes and With the increase on electrode surface area is calculated from theoretical calculations. Although this has also observed in the experiments, when the distance between electrodes is too high conductivity is reduced and according to that productivity rate is reduced.

In the experiments and calculations shows that designed generators can create the capacity of 20 m^3/h with porous plates. With same diameter and conditions but linear electrodes can create %32 less productivity.

In conclusion designed generator showed that in theory and in experimental work it can work efficiency electrolysis than any other before created.To have the system work and to be evaluated in real form the system must be set in the calculations made in theoretical spaces. This way it will show that it is far more efficient than any other hydrogen producer and it will be ready for presentation.

4. Conclusions

According to the assessments made continuously applying of tension is more useful than intermittently applying. Also increased in proportion to the amount of hydrogen produced was determined with use increasing the spacing between the electrodes and the porous electrode. 3,9-4,6 kW/h energy is needed to producing to 1 m^3 hydrogen gas.

According to theoretical calculations and experimental studies, this value will be up to 2,85 kW/h with new electrolyser design. Consequently, designed electrolyser will be operate higher efficient than the other electrolyser. This research was supported by Duzce University BAP Project.

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