A New and Efficient Electrolysis Dry Cell Design for Industrial Applications

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Abstract— In this study, the hydrogen evolution reaction (HER) was performed with dry cell to produce hydrogen gas. A new and efficient dry cell was designed to generate HHO gas (also is called as hydroxy or oxyhydrogen). The water electrolysis cell is bound to a strong electrolyte, which may be alkaline and acidic. KOH is an alkaline type solution which has higher decomposition rate, so it has been selected for experiments. Electrodes used in the dry cell are an important part of hydrogen production. Shape and numbers of them affect the cell efficiency. In order to achieve more efficient rate of hydrogen production, the magnetic field is applied to the electrolysis cells. A magnetic field has been added to the system by permanent magnets to increase hydrogen production. With the effect of the Lorentz force, the rate of electrolysis in the system has increased, as a result of which hydrogen production has also increased. This study investigates power consumption changing with the magnetic field. Applying magnetic field shows the decreasing the power consumption. To evaluate the system efficiency, MMW (milliliter/minute/watt) value is considered. In terms of MMW result, our cell is more effective.

Keywords: Water electrolysis, Dry Cell, HHO, Hydrogen production, Magnetic field

I. INTRODUCTION

Alternative energy systems containing hydrogen are a promising candidate for solving global environmental problems and meeting the increasing energy needs. Hydrogen is mostly considered a potential energy carrier in this system because there is no greenhouse pollutant gas (such as carbon dioxide) produced during the energy release process. Hydrogen energy conversion technologies play an important role in green energy development to overcome environmental problems. One of these technologies, the electrolysis of water, is an important technology to produce high purity hydrogen and oxygen gas. For this reason, how to increase the water electrolysis efficiency is one of the issues worth further investigation [1-4].

HHO (hydroxy or oxyhydrogen) cells are classified in two main groups. One of them is wet cell while other is dry cell. In wet cell, solution and cell are in the same box. So, corrosion can easily occur on surface of used materials. Because of that reason, cell efficiency starts to decrease after a while. With the HHO dry cell design, they are outside of the water/catalyst solution which is stored in a separate reservoir and recirculated by the HHO dry cell, this help in producing more HHO gas and less heat (steam). Water solutions with NaOH or KOH are used due to having higher electrical conductivity of these solutions. The KOH solution is considered as the best available one because of its high efficiency of HHO gas production whereas NaOH solution was used due to its low price and well accessible. Due to KOH advantageous, water solution with KOH was utilized for our experiments. The HHO gas is widely used in the industry especially in the automotive industry (also welding and material processing) because of renewable energy property, Furthermore, HHO can be used in high flame application because it has quite high flame threshold. HHO dry cell is defined as converting water to the hydroxy gas. Mainly, HHO is that water molecule is split into its molecules by applying electrical current. The voltage that is applied in the system must be DC. Otherwise an AC-DC inverter should be preferred. [2-6].

In the literature, there are many methods to increase the efficiency of the cell such as ultrasonic waves, gravity, magnetic field ad optic field [7]. Cost effective and energy saving way is to use magnetic field. The reason for adding a magnetic field to HHO system for hydrogen production is to increase the electrolysis rate. Lorentz force is a force applied on a charged particle moving in an electromagnetic field. The charged particles will be forced in the direction perpendicular to the magnetic lines as the magnetic field and electric field lines are perpendicular to each other. Thus, the charged particles will be affected by the Lorentz force and the direction of movement of the particles will change. The Lorentz force also effects on movement of hydrogen bubble on electrode surface and decreasing ohmic resistance. Separation of the bubbles from the surface means that more hydrogen is generated. Therefore, an appropriate design of the magnetic field will provide a uniform flow area and an appropriate ion distribution between the electrodes which provides increasing in electrolysis rate and efficiency [8-11].

In the study, Kaya et al. [12] reported that magnetic field effects positively on performance of proton exchange membrane water electrolysis (PEMWE). Their cell performance was increased by 33% under the applied magnetic field as 0.5T (Tesla). This effect was explained by the Lorentz Force from the magnetic field.

Applied power can be calculated with magnetic field and without magnetic field as P=voltage*current. The difference between them is calculated by [13],

$$D=P_{magnetic}-P_{no\ magnetic} \quad (1.1)$$

So, increasing rate in the power is done by,

$$n= D/P_{no\ magnetic}*100\% \quad (1.2)$$

II. MATERIALS AND METHODS

In our experiment, the solution with KOH is performed as electrolyte. According to conducted previous studies, the electrical conductivity increases as the weight percentage of the electrolytic solution increases. However, the conductivity at 40 wt.% and 50 wt.% is lower than that at 30 wt.%. It indicates that the hydration of KOH will increase as the concentration is higher than 30 wt.%, and results in the decrease of electrical conductivity [9,10].

Delrin (POM) material is used for end plates (two pieces) the size is 160mm*120mm and 10mm thickness that white color was preferred. There is one through hole on each plate that one is for inlet and other is for an outlet. In our setup, we have used 3 types of stainless-steel plates. We use them for negative electrode, positive electrode and neutral plates. The number of six plates is chosen for neutral which has rectangular shape as 120mm*80mm and 0.5mm thickness. The number of positive and negative plates is one respectively, moreover the shape of it is same as neutral plates, however they have 2mm thickness and a tail on the corner because of conduction (electrical connection) for anode and cathode. All these plates were manufactured by Yb doped continuous wave fiber laser. We implemented two types of bolts. 14 of them is used for compression of end plates, while 2 of them is used for anode and cathode connection. The number of 32 washers and 20 pieces of nuts is essential for mechanical compression. Before compression the plates, number of 9 rubber gasket is also placed between them to protect water isolation.

In Fig. 1, all required parts of the dry cell are shown. After complete setup, electrical connection will be coupled. Constant DC voltage is implemented between cathode and anode as positive and negative respectively. There is a water tank that contains solution with KOH and water. It is connected to input hole through pneumatic hose on the delrin. The output hole on the other delrin should be connected to the water tank. At that point, we can see a mixture of hydrogen and oxygen gasses. During hydrogen gas production, change in current and flow of gas has been noted. After a while, there will be saturation. At that time, the system should be shut down otherwise it will be warming up.

Fig. 1: Components of dry cell.

A. Dry Cell Setup and Design

System design is drawn in a CAD software. After the final design, we started to manufacture parts. Neutral plates, electrodes and rubber gaskets as black color are sandwiched tightly between delrin plates (seen as green) as in shown in Fig. 2.

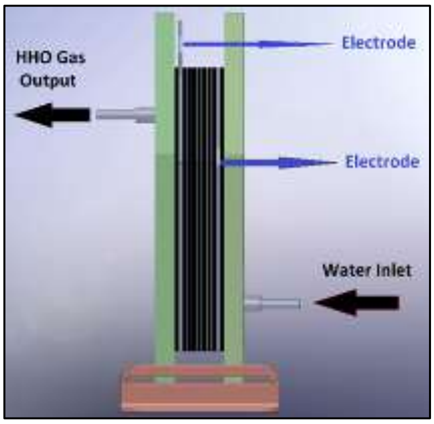

Fig. 2: CAD design of the cell

In our setup, there are 7 water compartments. According to literature, voltage between two successive plates can be almost 2 volts due to over potential effect. So, we may apply nearly 14 volts between two electrodes.

B. Experimental Setup

In addition to the dry cell, DC power supply, water tank (for KOH solution), HHO tank (to collect HHO gas), flashback arrestor for protecting the cell and blue pneumatic hose as shown in Fig. 3. Moreover, the assembled dry cell is illustrated in Fig. 4. When switch on the power supply, the cell immediately generates HHO gas. During the experiment, the applied voltage is constant. Whereas current starts to increase. It means that HHO production is going on. After a while, the system begins to warm and HHO production efficiency decreases.

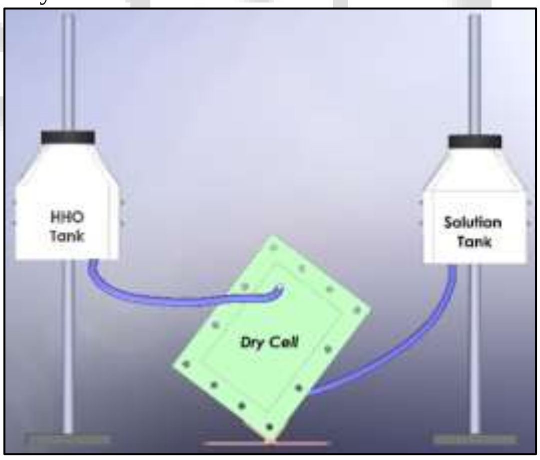

Fig. 3. Experimental Setup

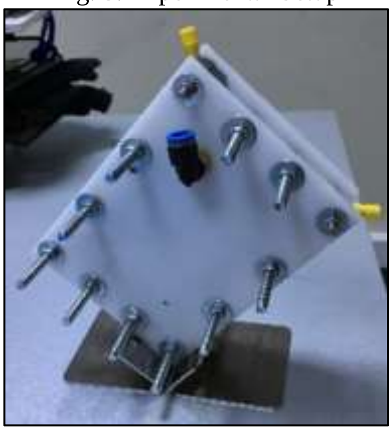

Fig. 4: Manufactured dry cell

III. RESULTS AND DISCUSSION

The aim of this study is to design of a new dry cell system for industrial applications. Water electrolysis was performed for hydrogen evolution reaction that is done by the HHO dry cell. We studied parameter optimization to enhance the efficiency of the cell. Certain important parameters are material selection (resist to corrosion), electrode selection (in terms of shape, size and thickness), supplied voltage, controlling heating problem and solution (type and percentage). We have applied magnetic field to increase the efficiency of the system, although there are many methods to enhance the efficiency of hydrogen production. Because there is no needed additional energy, just use magnets. This is the main advantage to use them. Strength of the applied magnetic fields are 3T and 6T. Magnets are placed side of our setup as shown in Fig. 5.

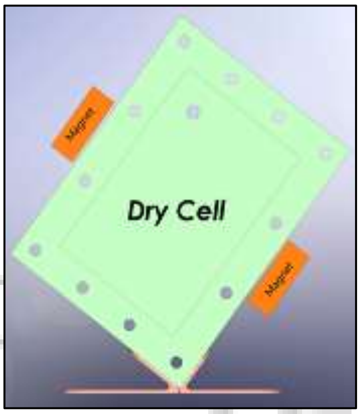

Fig. 5: Dry cell with magnets

According to experimental results, we got results for without magnetic field as in Table 1. Electrodes were manufactured by 304 stainless steel. Voltage of 13.8V was constantly applied between them. Distance between plates were chosen as 2mm and 3.5mm. KOH used as electrolyte which has concentration of 1wt.%, 3.5wt.% and 10wt.%. Flow rate of the output HHO gas is the maximum for 2mm of plates distance and 3.5wt.% of KOH solution that is 230 ml/min for average of 5 minutes. Temperature of the electrolyte was 16°C before no electricity supplied. Once the cell was started to generate HHO, the temperature of the cell was 18°C and 35°C at 5 minutes and at 20 minutes respectively. So, 2mm plate distance and 3.5wt.% KOH concentration are the best and highest for generation HHO gas.

Plate distance (mm)	Electrolyte (%)	Current (A)	Generated HHO (ml/min)	
			5 min	20 min
2	%1 KOH	3	170	290
2	%3.5 KOH	3,5	230	350
2	%10 KOH	4,6	210	330
3,5	%1 KOH	2,7	150	230
3,5	%3.5 KOH	3	210	350
3,5	%10 KOH	4,1	170	250

Table 1. Experiment results without magnetic field.

In Fig. 6. generated HHO is demonstrated for plate distance of 2mm and KOH electrolyte concentration of 3.5wt.% at an applied voltage of 13.8V. In this study, these parameters are taken as reference for next experiments. Once the cell started, 230 ml/min of HHO was generated at 5 min. At 50 min, flow rate of the HHO gas started to be constant due to heating of the system and bubble accumulation.

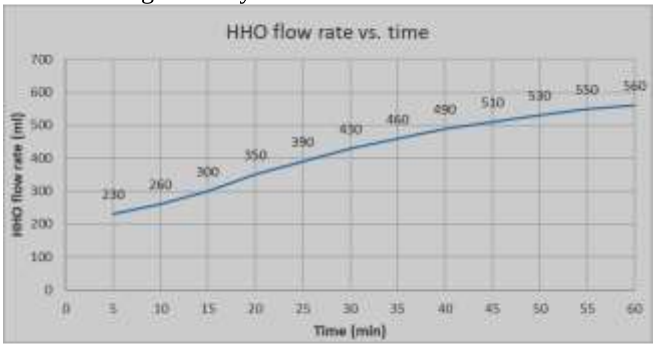

Fig. 6: Generated HHO gas in terms of time at constant voltage

The cell was tested for 6 hours. By adding a magnetic field to the system, the flow rate of the HHO is enhanced linearly. In order to supply magnetic field, a permanent magnet is used that has magnetic strength of 3T and 6T. When 3T of magnetic field was added to the system, the generation of HHO was 370 ml/min after 20 min. Whereas 400 ml/min of the HHO gas was obtained for applied 6T of the magnetic field. In Table 2. measured current with ampere was examined for without magnetic field, with 3T and 6T. Applied magnetic field positively effects on the performance of electrolysis cell. At 10min, the current was measured 2.5A while it was 2A and 1.9A for applied 3T and 6T respectively. It means that power consumption of the cell is decreasing with increasing magnetic field strength. Power consumption is 34.5 Watt for without magnetic field at 10 min while it is 27.6 watt and 23.5 watt for with 3T and 6T, respectively. The cell has energy saving almost 20% and 32% for applying magnetic field of 3T and 6T. Overall energy efficiency is nearly 10% and 23% under 3T and 6T respectively that is calculated by using Eq. (1.2). For 6 hours, the cell was working with stable and low power consumption compared to without magnetic field.

Time (min)	Current (A) (without magnetic field)	Current (A) (with 3T)	Current (A) (with 6T)
10	2,5	2	1,9
15	3,1	2,7	2,3
20	3,5	3	2,7
25	3,7	3,2	2,9
30	4,1	3,5	3
35	4,2	3,9	3,2
40	4,4	4,1	3,5
45	4,5	4,1	3,6
50	4,8	4,2	3,7
55	5,3	4,6	3,9
60	5,7	5	4,1
120	5	5,2	4,3
360	5,5	5,3	4,3

Table 2. Current changing with and without magnetic field

In Fig. 7. shows the graphical view of the Table 2. Obviously, applied magnetic field has a significant effect on the energy saving. We use constant applied voltage, so the power is directly related with measured current. Especially, magnetic density of 6T has a huge impact on the power consumption demonstrated as yellow bar. Even if long working hour of the cell, the current changes is very minimal for 6T compared to 3T and without magnetic field. Applied 3T of magnetic field density has also positively effect on reduction in current as it is shown in green bar.

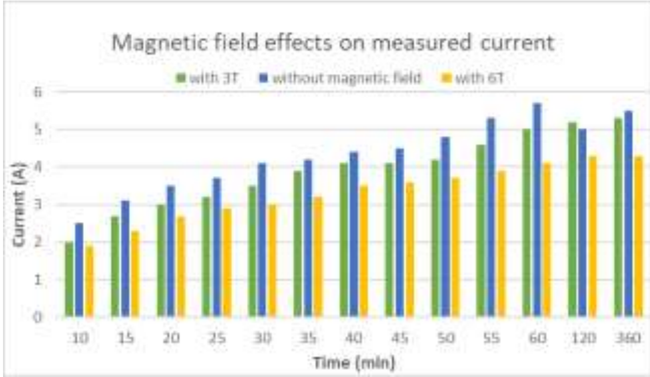

Fig. 7: Changing current with or without magnetic field at constant voltage

Energy consumption is critical parameter for energy sustainability and cost-reduction. The magnetic field effects the system performance, energy consumption and durability. In addition to it, flow rate of the HHO gas is increasing with increasing the magnetic field density as shown in Table 3. The magnetic field effects are explained by Lorentz Force that supplies bubbles removal from the electrode surface and decreasing in ohmic resistance.

Time (min)	Generated HHO (ml/min) (without magnetic field)	Generated HHO (ml/min) (with 3T)	Generated HHO (ml/min) (with 6T)
10	260	300	320
15	300	330	350
20	350	370	400
25	390	410	430
30	430	460	480
35	460	500	530
40	490	540	570
45	510	570	600
50	530	610	650
55	550	660	700
60	560	680	730
120	580	700	750
360	590	710	770

Table 3. Magnetic field effects on generated HHO gas

Efficiency of the electrolysis is calculated by one of the known ways as milliliter/minute/watt (MMW) that is related with ratio of the generated gas to the electricity consumption. MMW value is calculated incorrectly due to the temperature of the cell at higher values [14]. HHO generation efficiency is estimated by how much HHO is generated divided by energy input. Basically, it is calculated by how many milliliters generated per watt in the unit time. According to literature, MMW value of the HHO dry cell is known as 4.4 MMW to 5.65 MMW [15].

In our study, we have got 7.54 MMW for without magnetic field at 10 min whereas 10.87 MMW and 12.2 MMW for applied 3T and 6T, respectively. After 2 hours, the cell efficiency is almost 8.41 MMW under without magnetic field that is maximum value. On the contrary, the maximum value of MMW value is at 10 min for applied 3T and at 55 min for 6T. While the cell is working, its efficiency starts to decrease in terms of MMW but still the cell has higher efficiency under applied magnetic field density. Obtained results for MMW is detailly shown in Fig. 8. As it is shown in below figure, applied 6T has still highest MMW value for 6 hours.

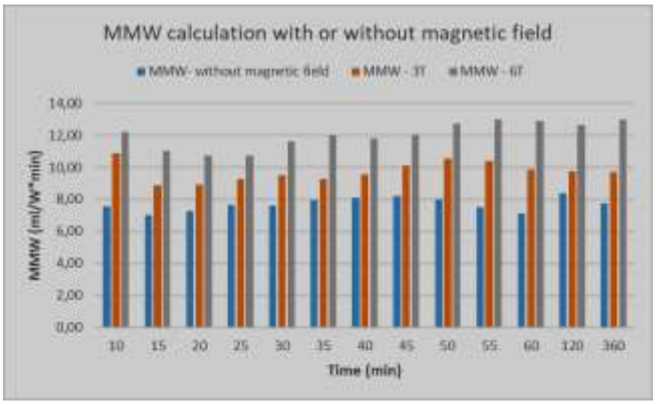

Fig. 8: MMW calculation with or without magnetic field at constant voltage.

IV. Conclusions

Hydrogen is accepted as a substantial energy supplier and carrier for future. A few methods are used to get hydrogen. One of the used methods is the water electrolysis. Electricity is essential energy to produce the hydrogen gas. It is the disadvantage of the water electrolysis. When electricity is supplied by renewable energy sources such as solar energy, so the method is quite applicable for industry and green energy. Our hydrogen generator has some unique properties especially for the industry. It has cost effective, efficient, maintenance is easy and flexible. Nowadays dry cells are widely used in automobiles. It supplies fuel saving for them. According our study, we use magnets to increase production efficiency. Of course, other ways can increase the efficiency of the dry cell. However, magnets work without any energy consuming which has 3T and 6T. Applying the magnetic field to the cell will help transport hydrogen bubbles from cathode surface. Thus, bubbles are not collected on the cathode surface and more bubbles can be generated. This means flow rate increases. The HHO cell efficiency is determined by the MMW value that is about produced gas over supplied power in a minute. Without magnetic field, the cell has almost as an average efficiency of 7.7 MMW for 6 hours. However, as an average of 9.7 MMW is obtained under applied 3T, besides 12 MMW is calculated under applied 6T. In future studies, we try to find optimized values in terms of electrode thickness, electrode surface area, shape and numbers of the electrode, percentage concentration of the solution, space between two consecutive electrodes and strength of applied magnetic field in terms of Tesla. We will have more efficient new electrolysis dry cell design and more portable for industry after optimization.

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