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Development and Performance Analysis of a Low-Cost Hydrogen Generation System Using Locally Available Materials

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Abstract

In this paper, a low-cost water electrolyzer is developed and its performance study is presented. Locally found materials are used to develop the electrolyzer. The electrolyzer has two cells connected in parallel and bipolar electrode configuration. In common, different cells are connected in series but for this electrolyzer parallel connection has been tested. A very thin polymer, Nylon-140 has been used as separator membranes for this electrolyzer. In separator membrane assembly, the designed geometry creates two separate gas channels internally which enables the direct collection of hydrogen and oxygen gas from the designated outlet port of the electrolyzer. The geometry excludes the need of external tubing into each cell-compartments to collect hydrogen and oxygen separately. The developed electrolyzer is found to be 42% efficient with its highest production rate of 227.27 mL/min. The purity of hydrogen is found to be more than 92% and justified with the burn test. The cost is 20 times less than the commercial electrolyzers. The development method and scheme can be helpful to popularize the small scale use of hydrogen in Bangladesh for various renewable energy applications.

Keywords: Split Type Water Electrolyser, Hydrogen Generator, Separator Membrane Assembly, Bipolar Plate, Gas Channel Separator, Gas Release Chamber.

I. Introduction

Electrolysis is one of the most popular methods for the generation of hydrogen. Advancement in methods has been immerged over time. Among all of these technologies, alkaline and polymer electrolytic membrane (PEM) based electrolyzers are widely studied.

Alkaline electrolyzers are simple compared to PEM electrolyzers. Both technologies require a direct current power source to operate. Mainly two categories of alkaline electrolyzers are available, unipolar and bipolar[1]. In, unipolar alkaline electrolyzer the electrodes are directly connected to power terminals. Anodes and cathodes are connected alternatively. The arrangement is set in a tank and electrodes are suspended one after another. Multiple cell operation can be facilitated in this arrangement by connecting each cell parallelly.

Required operating voltage ranges between 1.95 Vdc to 2.5 Vdc. Unipolar electrolyzers are very simple and easy to repair. Any problematic cells can be disconnected without altering the whole system functionality. Unipolar electrolyzers operate at low temperatures and have a low current density which implies some drawbacks, hence the most recent unipolar electrolyzers can operate for high-pressure hydrogen output (6000 psig).

Below equations 1 and 2 represents anode and cathode reactions for Unipolar and Bipolar electrolyzers.

Anode reaction:

$$4OH^-(aq) \rightarrow O_2(g) + 2H_2O(l) \qquad (1)$$

Cathode reaction:

$$2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq) \quad (2)$$

In bipolar electrolyzers, (often called filter pass) layers of electrodes are placed alternatively. It uses a separation membrane or diaphragm. Higher stack voltage is achievable by the series connection of cells[2]. As the cell layer is thin so bipolar electrolyzers are considerably smaller than the unipolar electrolyzers. High-pressure gas output and small size give advantages for various applications. Bipolar electrolyzers cannot be repaired without disassembling the whole stack. However, servicing is rarely required. In, earlier times asbestos is used as diaphragm but in recent days' manufacturers are using polymer materials.

Technological advancement for alkaline water electrolysis achieved an efficiency range of 64% to 70% using KOH electrolyte. Some commercial electrolyzer systems achieved 56% to 73% efficiency[3].

Advanced alkaline electrolyzers use an aqueous solution of KOH (25–30 wt%). KOH is very corrosive. In recent days, diaphragms or membranes for alkaline electrolyzers are being developed as composites objects. Ceramics or microporous materials are being used. Microporous polymer membranes, glass-reinforced poly-phenylene sulfide (PSS) compounds, or metal oxide composites are among them[4]. Less expensive metals (non-platinum-group metal) are used for electrodes. Porous nickel-based alloys are also used to increase electrode surface area[13].

PEM electrolyzers are advanced and costly devices. The efficiency of PEM electrolyzers are higher and use electrodes made of expensive metals like platinum. Polymer membrane serves as both the gas separator and ion conductor[5]. Figure 1 shows a PEM electrolyzer cell and reaction steps. Anode and cathode reactions are given in equations 3 and 4 respectively. PEM electrolyzers required high purity de-ionized water (1 MΩ-cm) for longer stack life[6]. The most commonly used membrane is Nafion. PEM

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electrolyzes also uses bipolar electrochemistry for multiple cell stack configuration[7].

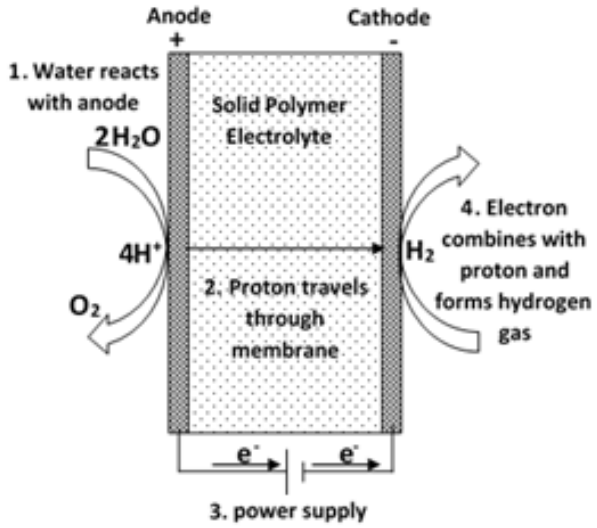

Fig. 1. PEM electrolyzer components and reactions

Anode reaction:

$$2H_2O \rightarrow 4H^+ + 4e^- + O_2 \qquad (3)$$

Cathode reaction:

$$4H^+ + 4e^- \rightarrow 2H_2 \qquad (4)$$

In PEM electrolyzers, oxygen is produced at anode side and hydrogen is at the cathode. High pressure across the membrane can be achieved. The current density is greater than 1600 mA/cm^{-2}.

In recent days, commercial PEM electrolyzers have efficiency[8] ranges between 51% and 83%.

PEM electrolyzers have advantages over alkaline electrolyzers. Due to increased efficiency, the operating cost is lower. However, many other important factors limit the use of PEM electrolyzers. Platinum is a very costly metal as well as polymer electrolytic membranes. Lifetime is a critical issue of PEM cells. Sudden start-stop affects longevity[9]. PEM electrolyzers have components made of stainless steel. Metallic cations dissolved in water contaminates the membrane by the exchange of proton. It reduces the proton conductivity. Catalyst loading improves the lifetime of the cell but it increases the cost again.

Recent PEM electrolyzers are also having the same configuration as like as 30 years ago. Thick Nafion 115 and 117, black platinum electrodes with a high load of catalysts, and thick graphite made bipolar plates[10].

Polymer electrolytic water electrolyzers (PEWE) has a variety of range of application. Starting from 100 watts' small laboratory scale to 6 MW input power capacity. Low capacity (below 1 kg (H2)/h) devices are available in the market for decades but not optimized in terms of material cost and the Levelized cost of hydrogen. Short life is also a factor that causes the increased replacement cost of components. Due to the high expenditure, large scale applications are not very popular yet. The largest PEWE installation is located in Mainz (Germany) which is a 'power to gas' plant. The input capacity is about 6 MW.

Applicability of PEWE in the energy sector requires more optimization of costs. Durability, materials, operating conditions and economics should be improved.

Hydrogen generation projects in developing countries would require low-cost methods. Water electrolysis is the most convenient and easiest method for hydrogen generation. Commercially available PEM electrolyzers are expensive[11]. A standard PEM electrolyzer costs about 53000 BDT excluding VAT and other charges. Short term storage methods are also very important for the proper use of hydrogen gas along with safety devices. It is evident that in the context of developing countries PEM electrolyzers are not economically viable for small and medium scale applications. On the other hand, the prospect of hydrogen generation using RE sources is reported to be worthy. Hence, this research aims to develop a low-cost hydrogen generator by indigenous materials and local technology that can be run by using renewable energy (RE) sources. A very common electrolyte sodium hydroxide (NaOH) is used for electrolysis.

Electricity can be used to produce hydrogen to store energy. Now a day, hydrogen is being treated as a renewable energy storage[12]. Excess electricity is used to produce hydrogen to store energy. Later on, it is used to produce electricity by using fuel cells on a requirement basis. Fuel cell-based power plants are already in existent. The potential of hydrogen as clean energy has been assessed and considered very promising for the world as well as for Bangladesh[13]. Apart from this hydrogen is experimented for the use in Biogas up-gradation through methanisation process. Results show that the methane content of biogas can be increased by up to 96% by converting carbon dioxide inbounds in reactor[14-15]. In this research, a low-cost electrolyzer is developed using locally available materials. Besides this, the performance of the developed system is tested.

II. Schematic of the Developed System

The hydrogen generation system, developed in this research, consists of several parts as shown in figure 2. Renewable energy sources considered here are mainly solar photovoltaic or wind energy. This research does not deal with the development of any power source and control units. However, the system requires these as vital components. The hydrogen generator is built to operate on the NaOH solution. The generator unit is the central component of the system. Electrolyte mixed water is filled in water tanks that hold the solution and work as a primary gas collector. There are two types of primary gas collector. As this generator splits water and delivers two gases separately it requires two different primary gas holders, one for oxygen and another for hydrogen. Hydrogen is collected

from one of the primary gas collectors and channelled into a filter. The filters itself works as the gas release chamber. Finally, hydrogen is collected from the gas release outlet.

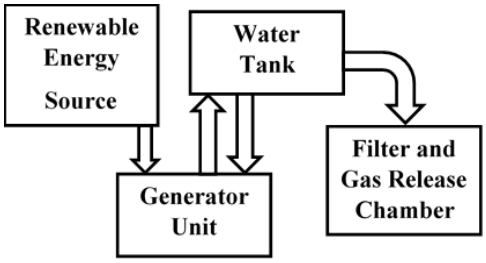

Fig. 2. Block diagram of the composite system

The block diagram presents a high-level description of the overall system components. Detail descriptions are given in the following sections.

Generator Unit

Water is broken inside the generator unit using electricity. The components of the generator are electrodes, gas channel separators, membranes, inlets, and outlet ports, frame, and bolt.

Electrode

Two types of electrodes are developed and used to build the electrolyzer. There are in total of 9 electrodes. Three of these having a connection lead for electrical power input. Other plates or electrodes do not have any lead. Figure 3 shows the electrodes. Electrodes are made of stainless steel. The grade of steel is 316L. The thickness of each plate is 1mm. Figure 3 shows the dimension of each plate. There are three holes on each plate. Upper two are designated for different gas passage and the bottom one is for solution mobility.

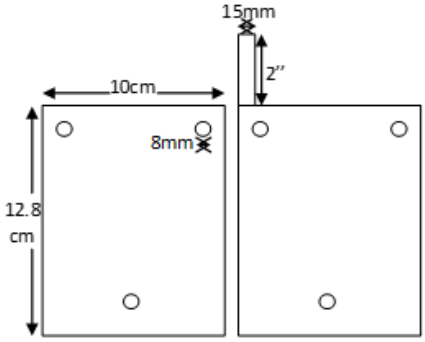

Fig. 3. Electrode plates

Gas Channel Separator

Gas channel separator is a unique and new technique for low-cost water electrolyzers. In common electrolyzers, separate delivery of hydrogen and oxygen is not facilitated. The developed generator has an assembly of electrode separator and membrane that keeps continuous separation of hydrogen and oxygen from the very beginning of bubble formation. Figure 4 shows the separator with a specific dimension used for this development.

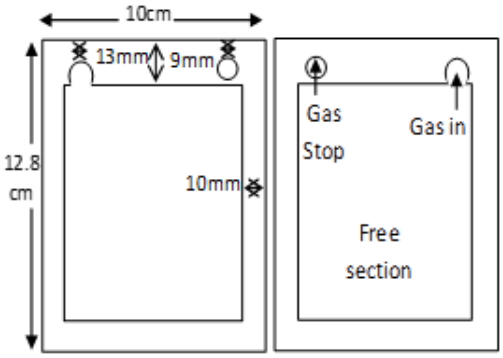

Fig. 4. Gas Channel separator

On the body, each separator has two distinct holes. One is open vertically so that the gas can move up to the passage denoted as gas in. another hole is closed by its periphery to block gas from the same compartment marked as the gas stop. The thickness of the separator is about 2 mm.

The function of the gas channel separator is to separate the electrodes from each other thus making a compartment of about 45.72 cm^3 (height 12.7 cm, width 9 cm, thickness 0.4 cm).

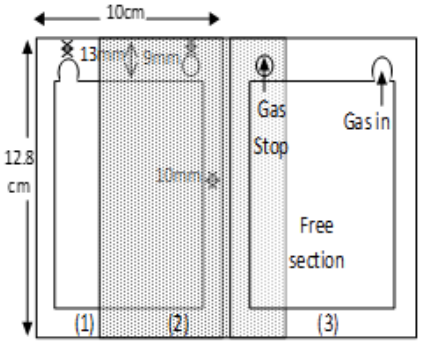

Fig. 5. Separator Membrane Assembly

Separator Membrane Assembly (SMA)

The most important part of this electrolyzer is the electrode separator membrane assembly. The separator membrane assembly (SMA) is placed one after another. The right side separator is in a vertically flipped position from the left side. In between them, the membrane is placed. Figure 5 shows the separator membrane assembly. The membrane is a nylon 120 plain sheet. The membrane allows the electrolyte solution to pass through all the compartments but it restricts any gas bubbles to pass through. This generator is a nine plate module. A total of eight SMAs are used for the configuration. One SMA is placed between two electrodes. This can be compared with the electrode membrane assembly of commercial polymer electrolytic membrane (PEM) electrolyzers.

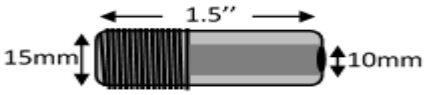

Fig. 6. Inlet and outlet ports

Inlet and Outlet Ports

There are three inlet and outlet ports on this device shown in Figure 6. The ports can serve as inlet and outlet at the same time. But the hydrogen outlet and oxygen outlet are deployed separately. All the ports are the same in size and design. These are made of PVC fiber having a 10mm channel cantered to its body. These are placed in such a way that the holes on the outermost electrode plates can access the port channel.

Frame

Two PVC sheets are used to frame the device. About 0.9 cm thick sheet is used to construct the frame. The function of the frame is to hold all electrode plates along with separator and membrane. There are drilled holes on both frames periphery as shown in figure 7. Bolts and nuts are used with metal washers to adjust and match the form of the design. This arrangement prevents any leakage. On the front sheet, two holes are for hydrogen and oxygen. The back sheet has one hole for purging electrolyte solution.

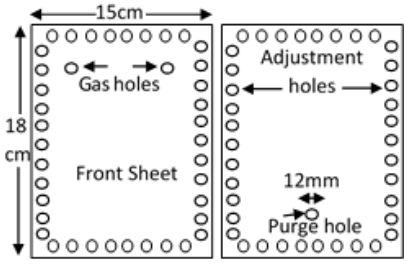

Fig. 7. Frame

Solution Tank Oxygen and Hydrogen chamber

Two identical 750 mL jar is used as solution tanks for laboratory experiments. Two different gases are accumulated in two different chambers. Tanks hold and pour the liquid into the electrolyzer through the drain port. Shown in figure 8.

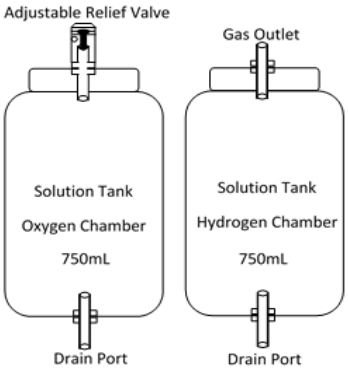

Fig. 8. Oxygen and Hydrogen Chamber

Gases are generated within different compartments of the electrolyzer and travel through the drain port in the form of bubbles to the gas chambers. In the oxygen chamber, one adjustable pressure relief valve is used. The adjustment is slightly higher than the working pressure. The system collects only hydrogen gas and releases oxygen into ambient after a certain pressure is built in the oxygen chamber. Hydrogen is directly collected from the upper portion of the hydrogen chamber.

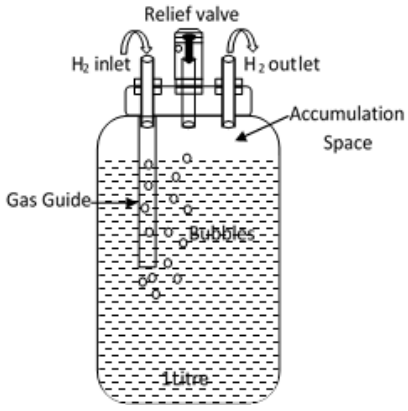

Fig. 9. Gas release chamber

Filter and Release Chamber

Hydrogen from the primary gas chamber is transferred to the filter. The filter is about 95% filled with clean water. The gas inlet of the filter is attached with a guide pipe submerged into the water. Hydrogen gas travels into the water and forms bubbles before accumulation on the top of the filter/ release chamber (figure 9). This filter provides safety for operation. If the gas is directly used for burning flashback may occur. There are a handful of reasons for flashbacks occurring in a pipeline[16].

This arrangement restricts flash to travel back to the generator. One pressure relief valve is attached to it as extra safety gear. Raw hydrogen is cleaned by the water and releases as a final output.

III. Electrochemical Operation

The developed device is two sets of electrolyzer connected in parallel within a single package. The voltage requirement thus remains lower for double output. Current consumption is higher for such a combination.

Drive Electrode, Floating Electrode, and Bipolar Electrochemistry

In this arrangement, there are two categories of electrodes present according to their functionality. The first category is the drive electrode shown in figure 10. In figure 11 it is shown that there are 3 electrodes which are having a physical connection (+/- sign marked). Drive electrodes have a direct connection to the power terminal either positive or negative hence, biased. Here, the device has 2 negative and 1 positive drive electrodes. The other type is floating electrode. Floating means that these electrodes are not having any physical connection to the power source[17]. It is only submerged into the electrolyte.

These floating electrodes experience an interfacial potential difference along with the electrolyte solution. The electrode

becomes equipotential conductor. This phenomenon is called bipolar electrochemistry. In electrolytic solution, polarization happens to any conducting material in an electric field[18]. This polarization creates a potential difference between the material surfaces. The potential is equal to the electric field multiplied by the size of the object.

In equation 1, P denotes the electric field value, E_a and E_c stands for anode and cathode potential of the source or drive electrode. Where d is the distance between two electrodes.

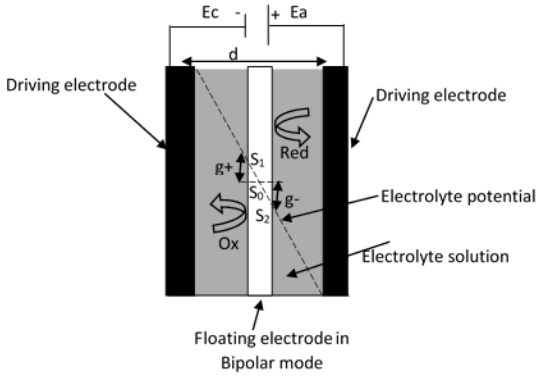

Fig. 10. Bipolar Electrochemistry

$$P = \frac{E_a - E_c}{d} \qquad (1)$$

$$g^+ = P(S_1 - S_0) \qquad (2)$$

$$g^- = P(S_2 - S_0) \qquad (3)$$

In equation 2, g^+ is the potential driven by the anode, S_1 is the potential point distant from S_0, the center of the object. Similarly in equation 3, g^- is the potential induced by cathode at S_2 point distant from S_0. Here, S_0 the center of the object[19].

The potential difference depends on the position of the electrodes in the electric field created by the drive electrodes. When this potential difference becomes equal to electrolysis voltage[20] then reduction and oxidation reactions start at the surfaces. If the oxidation reaction occurs at one side, the reduction is coupled simultaneously at the other surface.

In this device each electrode is positioned having an equal separation from each other hence each electrode has equal potential difference across them. Here, 10.6 volts are applied so each pair has 2.65 volts which are sufficient for electrolysis.

In this developed electrolyzer there are 8 compartments where a positive surface and a negative surface are formed face to face. Each such compartments are divided by a membrane. The negative surface (cathode) attracts positive ions (cations) (H^+). Here, cations (H^+) receive electrons (e^-) and form H_2 gas. Here, the reduction reaction happens (eq. 4).

The reaction in Cathode:

$$2\,H^+(aq) + 2e^- \rightarrow H_2 \qquad (4)$$

On the other hand, in the positive surface (anode) oxidation reaction occurs. Oxygen gas is generated by braking the water molecule collecting electrons to complete the circuit (eq. 5)

$$2H_2O(l) \rightarrow O_2(g) + 4H^+(aq) + 4e^- \qquad (5)$$

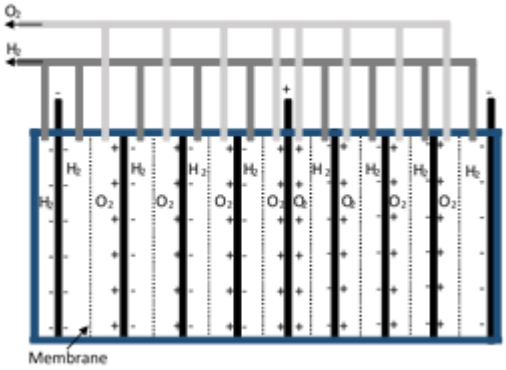

Fig. 11. Internal Operating condition

The generation of hydrogen and oxygen occurs at two distinct surfaces separated by a membrane and thus forms two different gas columns in the same compartment. Bubbles cannot pass through the membrane thus stays separated. All hydrogen columns and all oxygen columns are connected separately through SMA which forms separate hydrogen and oxygen channel. This arrangement enables the feature of pure hydrogen generation.

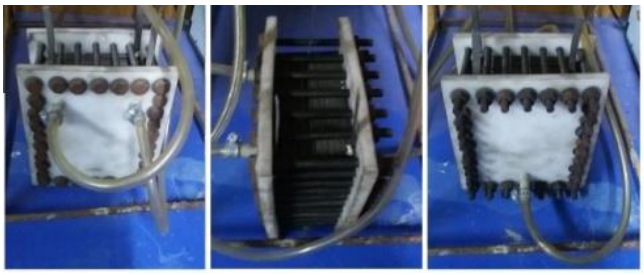

Fig. 12. Developed Electrolyser

IV. The Complete System

The complete hydrogen generation system is comprised of an electrolyzer, a solution tank, and a gas release chamber. Tanks are placed above the electrolyzer. All components are connected by using poly pipes PE 100. The chance of hydrogen leakage is negligible other than metal piping[21].

Fig. 13. Overall system for laboratory test

In the laboratory, a switched-mode power supply (SMPS) is used to operate the system and data collection. Produced gas is collected in jar and volume is measured with time intervals.

V. Performance Study of the System

The developed system is studied for three months. Gas production performance is tested for several molarities solutions. Solid sodium hydroxide pellets are used to prepare a solution. A laboratory-standard scale is used to weigh the pellets. De-mineralized water is used to make the solution. 5-liter solutions are made for each molarity by adding the required quantity of NaOH pellets. Data are presented in tables. The performance of the system and device is evaluated based on the practically gathered data sets. Electricity consumption is also presented here. The quality of produced gas is tested using a standard gas analyzer.

Table 1. Sample Data for 1.5 M NaOH Solution

Voltage (volts)	Current (amp)	Wattage (watt)	Production (mL)	Production rate (mL/min)
10.24	10.66	109.16	0	0.00
10.27	10.65	109.38	500	500.00
10.25	10.64	109.06	125	125.00
10.26	10.63	109.06	125	41.67
10.24	10.63	108.85	125	41.67
10.25	10.62	108.86	375	125.00
10.26	10.62	108.96	375	125.00
10.27	10.61	108.96	375	125.00
10.22	10.61	108.43	250	83.33
10.23	10.6	108.44	250	83.33
10.22	10.6	108.33	500	166.67
10.13	10.6	107.38	375	125.00
10.15	10.6	107.59	375	125.00
10.15	10.6	107.59	500	166.67

Gas is produced up to 5000 mL and each data element is recorded after three minutes of interval. For a 1.5 M solution, the electrolyzer's electricity consumption rate is about 108.58 watt on average where voltage and current are respectively 10.22 volts and 10.62 amps (Table 1). The data collection period is about 35 minutes where a total of 4250 mL hydrogen is produced that implies the overall production rate is about 121 mL/minute where three minutes' average is found to be 141 mL/minute.

Table 2. Sample Data for 1.0 M NaOH Solution

Voltage (volts)	Current (amp)	Wattage (watt)	Production (mL)	Production rate (mL/min)
12.15	10.67	129.6	0	0
12.14	10.66	129.4	480	160.00
12.05	10.65	128.3	395	131.67
12.06	10.64	128.3	500	166.67
12.02	10.63	127.8	475	158.33
11.97	10.62	127.1	400	133.33
11.95	10.62	126.9	500	166.67
11.93	10.62	126.7	750	250.00
11.88	10.62	126.2	500	166.67
11.85	10.61	125.7	750	250.00
11.81	10.61	125.3	250	83.33

Table 2 presents similar data for 1.0 M solution. Data is taken for 28 minutes for this solution. 5 L gas is produced within this period that results in a production rate of about 178.57 mL/min. Three minutes' average rate to be 166.67 mL/min. In this run, the electricity consumption rate is found to be 127.43 watts.

Table 3 shows data for 0.5 M solution. About 22 minutes were required for 5 L gas production that indicates a higher production rate for this solution.

Table 3. Sample Data for 0.5 M NaOH Solution

Voltage (volts)	Current (amp)	Wattage (watt)	Production (mL)	Production rate (mL/min)
11.31	10.63	120.23	0	0.00
11.28	10.63	119.91	875	291.67
11.28	10.62	119.79	1125	375.00
11.24	10.62	119.37	750	250.00
11.23	10.62	119.26	550	183.33
11.20	10.62	118.94	450	150.00
11.18	10.62	118.73	500	166.67
11.16	10.62	118.52	625	208.33
11.16	10.62	118.52	125	125.00

The electrolyzer consumes electricity at the rate of 119.28 watts and the production rate is about 227.27 mL/min. Three minutes' average rate to be 194.44 mL/min.

Table 4. Sample Data for 0.25 M NaOH Solution

Voltage (volts)	Current (amp)	Wattage (watt)	Production (mL)	Production rate (mL/min)
13.07	10.67	139.5	0	0.00
13.16	10.65	140.2	460	153.33
13.14	10.64	139.8	575	191.67
13.08	10.63	139.0	625	208.33
13.04	10.62	138.5	500	166.67
13.00	10.62	138.1	450	150.00
12.95	10.61	137.4	400	133.33
12.92	10.6	137.0	525	175.00
12.88	10.6	136.5	375	125.00
12.84	10.6	136.1	500	166.67
12.8	10.6	135.7	500	250.00

Table 4 shows data for a 0.25 M solution. About 29 minutes were required for 4910 mL gas production. The power consumption average is found to be 137.95 watts and the production rate is about 172.41 mL/min. Three minutes' average rate to be 156.36 mL/min. Table 5 shows the calculated values that are used to find the operational efficiency of the electrolyzer. The calorific value for 1 gram of hydrogen is about 150 kJ in standard condition.

Table 5. Calculated values for Operational efficiency

Molarity	Electricity consumption in Jules	Gas production in Jules	Efficiency in %
1.5M	228165	56928.75	24.95
1M	214032	66975	31.29
0.5M	157461.3333	66975	42.53
0.25M	240040.9091	66975	27.90

One liter of hydrogen gas weighs about 0.0893 grams. These values are used to calculate the calorific value of

produced hydrogen over the operation time. The highest efficiency is found to be 42.53% for 0.5 M solution and the lowest is found for 1.5 M solution. A higher molarity solution can reduce operational efficiency. The gas passage is an important factor for the greater gas production rate. 1.0 M and 0.5 M solutions are moderate to choose for longer operation.

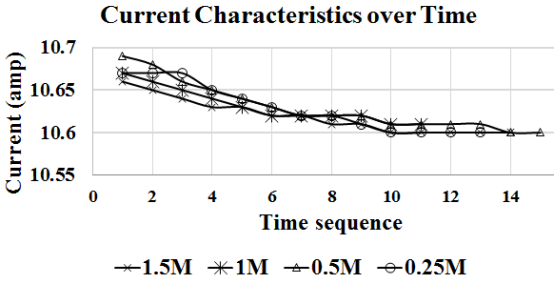

Fig. 14. Current Characteristics

During the electrolyzer operation, it is observed that with the increase of operational time the current consumption is decreased for all molarities solutions shown in figure 14. This is due to the stand in bubble formation which results in the operation beyond linearity. This implies an increase in internal resistivity[22]. The gas production characteristics for different molarity solution are shown in figure 15. The data is graphed according to the data collection sequence that is named as time sequence where bars in the graph show cumulative production values found in an instant.

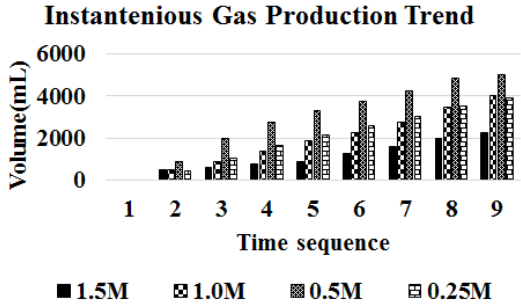

Fig. 15. Instantaneous gas production trend

The quality of produced gas is measured by using a standard gas analyser. It is found that about 92.5% pure hydrogen is generated by the electrolyzer while testing. Here, Carbon dioxide and oxygen are found in the mix because of the initial accumulation of ambient gases in the purge pipe of the analyzer.

However, the gas quality is examined through a burn test. Produced hydrogen is pure enough for continuous burn without any explosion. The mix of oxygen in the produced gas would result in an explosion. The flame color is brown due to the brass made burner head.

VI. Comparison with commercial PEM Electrolyser

The price of commercially available PEM electrolyzers is much higher than the developed electrolyzer. The developed device has a trade-off on the wattage that results in lower efficiency. The reduced efficiency might occur due to the resistivity of electrode plates and separator membranes[23]. Stand in bubbles can also increase resistance. Impurity in solution has an impact on performance[24]. Fouling may occur on membrane surface which significantly reduces the conductivity. During the test, the same solution is used several times. The test environment was not dust free and the components of the system were not kept in an enclosed compartment. So the dust particle might have got mixed with the solution. These could be the major reasons for having a low efficiency. Increasing the thickness or size of steel plates could reduce the resistance. The external pumps can be used to prevent the formation of the stand-in bubble and thus could improve the performance.

Table 6 shows the comparison against a commercial electrolyzer. The production rate and electricity consumption of the developed electrolyzer are higher concerning the commercial PEM electrolyzer. Due to the lower efficiency of the developed device the operating cost would be higher. But for log run applications like projects, having 25 years' life cycle, these low-cost devices would minimize the production cost of per kg hydrogen[25]. Initial investment and replacement costs would be considerably lower. Operating costs include electricity, water price which would be the same for both the devices. The only difference is the cost of sodium hydroxide pellets. Sodium hydroxide is available and not a very costly chemical (BDT 900/kg). The difference between Initial investment and replacement cost would cover the operating cost for long run projects. For a 1 kW system, the initial investment would be BDT 1494583 for the imported PEM electrolyzer whereas the locally developed device would cost nearly BDT 20000. Any replacement of PEM electrolyzers can increase the cost drastically. At present best PEM electrolyzers can run for 40000 hours which is equivalent to 4.5 years[26].

Table 6. Comparison values and comments

Features	Locally Developed Electrolyzer	Commercial Model (QLC-120 PEM Electrolyzer)
Price	BDT 2500	BDT 53805 (without port tax and other fares)
No Of Cell	2	2
H_2 Flow Rate	227 mL/min	120 mL/min [19]
Power Supply	DC	DC
Wattage	120 watt	36 watt
Plate Size	128 cm^2	56.75 cm^2
Membrane	Nylon 140	Nafion PFSA
Metal	SS316L	Titanium Sintering carpet and precious metal electrode
Water	Distilled water and NaOH	deionized or re-distilled water
Efficiency	42%	74%

This run time requires higher catalyst loadings, thicker membranes and high-performance separator plates which

results in more cost. Any project having a lifetime of 25 years the electrolyzers are to be replaced a minimum 6 times. From this point of view, the developed low-cost electrolyzers would have an advantage in production expenses.

VII. Conclusion

Due to the use of platinum and polymer membrane, PEM electrolyzers become costly. A high price is a barrier to popularize the small scale hydrogen use in countries like Bangladesh. The use of hydrogen for small scale energy requirements is being increased worldwide whereas it is yet to practice in Bangladesh. The optimal design and development of low-cost hydrogen generator by local technology can contribute to the solution to find an initial replacement for high price PEM electrolyzers. The developed electrolyzer can deliver hydrogen at a rate of 227.27 mL/min. However, the efficiency is about 42% which is half of the advanced PEM electrolyzers. The quality of hydrogen produced by the developed device is reliable for energy conversion applications. The cost of the locally developed electrolyzer is 20 times less of that commercial PEM electrolyzer.

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