THE EFFECT OF pH CHANGE ON THE OPERATION OF ELECTROLYZER AND FUEL CELL

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***Abstract*—Hydrogen has emerged as a new hope in energy sector. Hydrogen can meet all short comings of fossil fuels and moves hand in hand with sustainable development idea. The extraction rate of fossil fuel has reached its peak plus its excessive utilization has put our earth under great danger of global warming. As a result, 21st century has observed a rapid increase in fuel cell production. Simple operation plus production of water and heat as bi product of electricity production has supported this investment. All Fuel cell technologies, their design and operation are discussed in paper. Pre-requisite for operation of fuel cell is continuous supply of hydrogen. Technologies are being developed for production of hydrogen in efficient way. Electrolyzer has been developed, that can convert water into hydrogen and oxygen. Various electrolyzer along with their operation is discussed in paper. For proper operation of fuel, proper functioning of electrolyzer is required. It has been observed that electrolyzer performance can be affected by various means. Change in pH during electrolysis of water has been observed as a major challenge in proper functioning of electrolyzer. As design of electrolyzer typically PEM electrolyzer makes it prone to atmospheric factors, electrolyzer as well as fuel cell gets greatly affected by it. For observing the impact of pH change and air components, a small scale solar electrolyzer is operated in open green lush campus of IIT BHU. pH change with respect to time is observed. For having exact idea of IIT BHU air quality, ion chromatography test is done. Ion chromatography test has provided an estimate of various ion and impurities present in air of the campus. Total ions interacting with electrolyzer in its whole operation is found out. The above experimental observation put forward all the shortcomings of electrolyzer at small scale. The calculated data of paper provide an important idea to design electrolyzer. Drop in fuel cell performance due to electrolyzer improper operation is also discussed. The paper has covered all the major problem that can be faced by a large-scale system by analyzing the impact at small scale. The inference made in the paper can play a very crucial role in designing a hydrogen fuel cell power generation system at large scale.**

Keywords—electrolyzer, pH, fuel cell, PEM

I. INTRODUCTION

The concept of sustainable development is the most discussed topic for past few decades. So the question arises what is this word sustainable development means. Basically, sustainable development means development of present generation in such a way that it should not compromise the need of future generation.

The recent trend of harnessing energy for development purpose has brought a major hurdle in this novel concept. According to various researcher and scientist if this scenario is continued, we will leave empty wells of petroleum and coal beds for our future generation plus a generation carrying oxygen chamber on their back will be followed.

Global warming has emerged as the biggest challenge to human race in past few decades. The rate of melting of polar ice caps and ozone layer depletion has reached its peak. The core of all these problems is the blind run of human race toward energy production. The basis of energy production is the fossil fuel. Our earth has been a rich source of coal petroleum and various other carbon rich compound. According to estimation about 70-80% of global energy requirement is meet up by fossil fuel. Taking in consideration the very basic step of energy production by fossil fuels that is combustion of fossil fuel.

$C + O_2 \rightarrow CO_2$

Since they are carbon rich so the basic compound produced in combustion is carbon dioxide. This carbon dioxide is the basis of all these problems. Along with CO_2 its various other derivative like CO etc. are produced, depending on combustion condition. Presence of nitrogen and Sulphur is also there in fossil fuel so

$S + O_2 \rightarrow SO_2$ & SO_3

$N + O_2 \rightarrow NO_2$ &NO_3

are produced after combustion. The Companies and Organizations Greenhouse Gas Protocol has put all these gases under greenhouse gas as these are the very root of all these problems. The recent data will show how the content of all these gases has increased in past few decades [1].

Still why we are running behind energy production by this mechanism. There is a novel concept of energy generation by non-conventional means like solar wind energy but the major drawback that they offer is the capital investment and the relative efficiency. According to solar energy production data about only 20-30% of trapped sunlight can be harnessed for electricity. On the other hand, fossil fuel-based energy generation offer about 2.5 times and even more efficiency offered by that non-conventional means plus the capital investment is relatively much lesser. All these factors have brought a serious need of a new technology which can meet all these shortcomings.

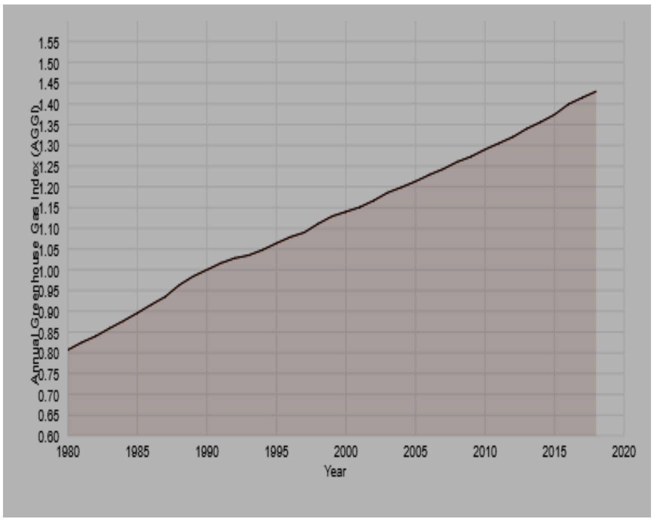


Figure 1: graph showing trend of annual greenhouse gas index for different years.

Source: LuAnn Dahlman

Actually, this problem would have been solved earlier but negligence and easy access to fossil fuel has deviated us from this. Our earth is rich in one more element other than carbon "Hydrogen the very first element of periodic table". In 1625 Flemish scientist Johann Batista van Helmont described hydrogen as a gas.140 year later British chemist Henry cavendish determined hydrogen as distinct chemical element.in 1800 William Nicholas and sir Anthony discovered a process of electrolysis in which they have observed that on passing electric current through water ,it got split into oxygen and hydrogen.40 year later Christian Fredrich Schoenlein worked on the reverse mechanism and found out that ,on combining hydrogen and oxygen electricity and water is obtained. That was the major achievement in the field of hydrogen as fuel but it took a century to implement it when Rudolf Erren first attempted to replace combustion engine with hydrogen-based technology.

The hydrogen as fuel then started catching the eye of human race because of the advantages offered as when hydrogen undergoes combustion

$H_2 + O_2 \rightarrow 2H_2O$

Water is obtained means no any greenhouse gases are yielded due to combustion of hydrogen. It was in 1990 when very first solar powered hydrogen production plant was established. As hydrogen as fuel concept flourished, it brought the concept of fuel cell and the mechanism of hydrogen production flourished.

II. Fuel Cell: Operation and Types

Fuel cell is a type of electro-chemical cell which converts the chemical energy into electrical energy. In fuel cell basically the chemical energy of fuel hydrogen and oxidizing agent oxygen is converted into electrical energy with the pair of redox reaction. Along with the production of electricity water and heat is also produced. The potential of one cell is around 0.7 v ,that is why for practical application number of fuel cell are used in stack[2].The efficiency of fuel cell is around is around 40-60% but with suitable recapturing method of heat produced its efficiency can be made around 80-85%.Due to considerably appreciable efficiency nontoxic and hazardous bi-product the market of fuel cell is expanding its root.it was estimated in pike research that the fuel cell market will reach 50gw by 2020[3].

A. *Operation*

Basically, fuel cell consists of anode cathode and an electrolyte.at anode, catalyst causes fuel that is hydrogen to undergo oxidation reaction that generates positively charged hydrogen ion and electrons.

Anode: $2H_2 \rightarrow 4H^+ + 4e^-$

The ion flows from anode to cathode through the electrolyte and at the same time the electron flows from anode to cathode through external circuit containing bulb, producing direct current electricity.

At cathode another catalyst causes ions electrons and incoming oxygen to react and water is formed.

Cathode: $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$

The overall cell reaction can be given as

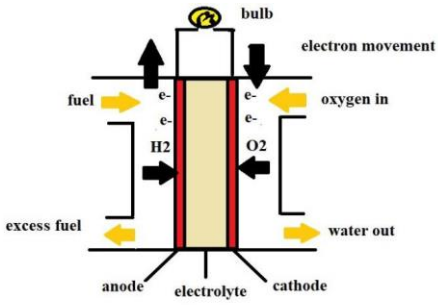


Figure 2: diagram showing fuel cell operation

Source: self

Overall: $2H_2 + O_2 \rightarrow 2H_2O$

B. *Types and design of fuel cell*

Fuel cell comes in variety of design and types but overall their functioning is similar. They all consist of anode cathode and electrolyte where redox reaction occurs and as a result fuel gets consumed and electric current and water is yielded.

Taking in consideration the design aspect of fuel cell there are various parameter

1.The fuel that is used Hydrogen is the most common fuel used

2.The electrolyte substance that can be made from various substances like potassium hydroxide, salt carbonates, and phosphoric acid [4]

3.The anode catalyst that breaks down the fuel into electrons and ions. Fine platinum powder is used for this purpose

4.The cathode catalyst that, converts ions into unwanted chemical waste, with water being the most common type of waste. Silicon is the most common cathode catalyst [5]

5.Gas diffusion layers that resists oxidization [5]

Different types of fuel cell are

- proton exchange membrane fuel cell
- Alkaline fuel cells
- Phosphoric acid fuel cells
- Molten carbonate fuel cells
- Solid oxide fuel cell

Type	Operating temperature	Electrical efficiency	Fuel source	Catalyst
PEMFC	~ 80°C	30 to 35%	Pure hydrogen	Platinum
AFC	100-200°C	35 to40%	Pure hydrogen	Platinum
PAFC	150-200°C	40%	Pure hydrogen	Platinum
MCFC	550-700°C	50 to<70%	Mostly hydrocarbon	Nickel
SOFC	450-1000°C	45-<70%	Mostly hydrocarbon	Perovskites

Table1: comparison between various types of fuel cell

Source: Amit Kumar, Tanvir Singh, Satnam Singh, Dr. Yunfei Liu [6]

It is quite obvious from above discussion that for continuous operation of fuel cell and supply of power to load there is requirement of a continuous supply of fuel. So, for commercializing fuel cell the major hurdle is fuel requirement. Recent decades have observed establishment of various plant for that purpose.

Fuel or better to say hydrogen production is the main area to focus. There are various mechanisms of producing hydrogen and a device called electrolyzer has been developed which can convert water in hydrogen and oxygen by means of electricity.

III. HYDROGEN PRODUCTION: ELECTROLYZER

It has been observed that for continuous operation of fuel cell there is requirement of continuous supply of fuel that is hydrogen. So, production of hydrogen is the main area to focus. The hydrogen production in total around the world is about 500 bill. Nm^3/year, mostly steam reforming.

For hydrogen production water electrolysis can be an important mechanism because of the various advantages offered like pollution free process. Currently only 4 % of hydrogen produced by water electrolysis [7][8]. Based on the electrolysis mechanism a device called electrolyzer is introduced. Electrolyzer uses electricity to break water into oxygen and hydrogen. There is anode and cathode which facilitates electrolysis of water via electrochemical reaction. It is very reliable method of hydrogen production as ultra-pure hydrogen is yielded. Considering the design of electrolyzer there is anode and cathode separated by electrolyte. Depending on the type of electrolyte used, various types of electrolyzer are there.

There are 3 major types of electrolyzers

- Alkaline electrolyzers
- Proton Exchange Membrane (PEM) electrolyzers
- Solid Oxide fuel electrolyzers

A. *Alkaline electrolyzer*

In alkaline electrolyzer there is basically two electrodes operating in a liquid electrolyte solution of Potassium of potassium hydroxide or sodium hydroxide. The electrodes are separated by a diaphragm, that separates the product gases formed and transports hydroxide ion from one electrode to other. The diaphragm is nonconductive to electron thus reduces the chance of electrical short.

In alkaline electrolyzer, a strong base is used as the electrolyte. The hydroxide anions are transferred through the electrolyte to the anode surface, where they lose electrons and oxygen gas is evolved. This electron then passed to cathode by external circuit where water is reduced and hydrogen gas is produced [8].

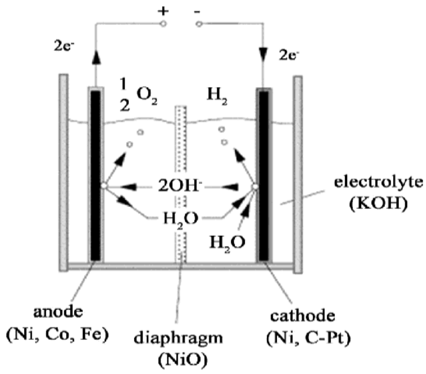


Figure 3: Diagram for alkaline water electrolyzer Source: Mohamed S. Elshokary [9]

The anode reaction and cathode reaction are given as follow

Anode: $2H_2O + 2e^- \rightarrow H_2 + 2OH^-$

Cathode: $2OH^- \rightarrow 1/2O_2 + H_2O + 2e^-$

Overall $H_2O \rightarrow H_2 + 1/2O_2$

B. *PEM Electrolyzer*

Proton exchange membrane electrolyzer has a solid polymer electrolyte which is responsible for the conduction of protons, separation of product gases, and electrical insulation of the electrodes [10]. The use of these electrolyzer was first observed in general electric in 1960s.The initial performances yielded 1.88 V at 1.0 A/cm^2.[11]

At anode water is oxidized and oxygen gas is produced along with hydrogen ion and electron. The electron is passed to cathode via external circuit while hydrogen ion is passed to cathode via proton exchange membrane. At cathode reduction process carried out. The incoming hydrogen ion gets reduced to hydrogen gas. Thus, hydrogen gas is obtained at cathode terminal.

Anode: $H_2O \rightarrow 1/2O_2 + 2H^+ + 2e^-$

Cathode: $2H^+ + 2e^- \rightarrow H_2$

Overall $H_2 + 1/2O_2 \rightarrow H_2O$

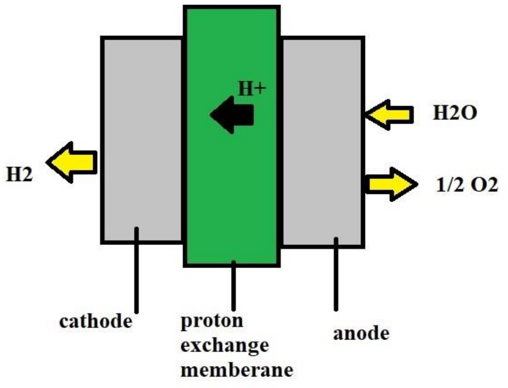


Figure 4: Diagram showing proton exchange membrane electrolyzer

Source: self

C. *Solid Oxide Electrolyzer*

Solid oxide electrolyzer uses by using a solid oxide, or ceramic, electrolyte to produce hydrogen gas and oxygen. It follows a regenerative principle for electrolysis of water. The operating temperature of solid oxide fuel electrolyzer allows high temperature electrolysis and occur between 500 and 850 °C.

The electrodes are of porous nature.to initiate the process steam is passed to porous cathode. As the voltage is applied, the steam moves to the cathode-electrolyte interface and is reduced to form H2 and oxide ions. The hydrogen gas then gets diffused through the cathode and is collected at the surface cathode as hydrogen gas. The oxide ions are conducted through the electrolyte. The electrolyte must be dense enough. At the electrolyte-anode interface, the oxide ions are oxidized to form pure oxygen gas, which is collected at the surface of the anode [12].

The reaction at anode and cathode half are given as

Anode: $O2- \rightarrow 1/2O2 + 2e-$

Cathode: $H2O + 2e- \rightarrow H2 + O2-$

overall: $H2O \rightarrow H2 + 1/2O2$

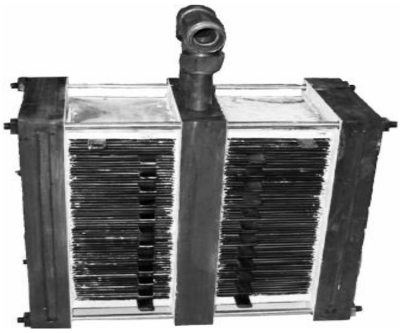


Figure 5: A typical practical solid oxide electrolyzer cell Source:(Diogo M. F. Santos; César A. C. Siqueira; José L. Figueredo) [8].

D. *Solar electrolyzer*

It is obvious from above that for production of hydrogen and oxygen, electrolyzer needs dc electric current. The electrolysis of water is achieved through the supply of dc current. So, to provide a continuous dc current a mechanism need to be developed. Adding battery or any other power sources for this purpose cannot be considered as novel approach because it requires replacement at regular interval depending upon usage. Plus, it will increase the capital investment for overall system construction. A typical solar electrolyzer is shown below

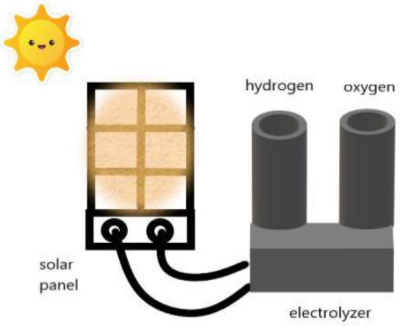


Figure 6: Diagram showing solar electrolyzer Source: self

There comes a concept of employing solar energy it this area. Solar energy can meet all the requirement and all make the system self-reliable, solar panels can be used to trap solar energy and it can be stored in solar cell. Typically organic thin film solar cells[13] and microcrystalline silicon thin film solar cells is used as solar cell the solar cell then fed its energy to electrolyzer. The electrolyzer further feed fuel cell with the produced hydrogen and oxygen.

IV. EXPERIMENTAL SETUP FOR DETERMINING THE FACTOR AFFECTING ELECTROLYZER PERFORMANCE

We have used solar PEM electrolyzer for this purpose and connected the electrolyzer with PEM fuel cell. The fuel cell is then connected with load box having a motor. For electrolysis purpose we have used distilled water and type 1 ultra-pure water. The whole system was kept in open atmosphere of IIT BHU campus. The experiment was carried out for 30 minutes and it was further continued for two more 30minutes of interval and reading of water level in oxygen and hydrogen chamber was noted. This water level was calibrated as the amount of hydrogen and oxygen generated. We have conducted three tests with the water left in oxygen and hydrogen chamber after 30 min of fuel cell and electrolyzer operation in open atmosphere.

A. *Observation*

After 30 minutes of electrolysis in open atmosphere a blackish deposition in oxygen chamber was noted. Taking this in consideration the same operation was repeated for two more 30-minute time interval with same water sample. It was observed that the speed of motor was slowing down in each interval.

The blackish deposition in oxygen chamber was the notable thing occurred. We tried to identify the reason for the above and performed

- pH test
- Ion chromatography test with ultra-pure type 1 water as reference

on the water left in hydrogen and oxygen chamber of fuel cell at environment lab of IIT(BHU). We have again conducted pH test of water left in oxygen chamber after prolonged process for 30-minute interval.

PH TEST

pH test of distilled water, water left in hydrogen and oxygen chamber was conducted. We have taken three reading for each sample for sake of accuracy. The pH test shown following values.

S.no	H_2 SAMPLE	O_2 SAMPLE	DISTILLED WATER	O_2 SAMPLE another 30 min)
1	7.87	7.25	7.28	7.12
2	8.04	7.28	7.37	7.15
3	8.13	7.23	7.40	7.08
Avg	8.01	7.25	7.35	7.11

Table 2:pH test result on water samples

ION CHROMATOGRAPHY TEST

Ion chromatography test is performed to determine the amount of cation and ion present in the sample. Since the whole experiment was carried out in open atmosphere so there is chance that environmental impurity may affect the experiment. We have conducted electrolysis process by type 1 ultra-pure water to eliminate the effect of the already present ions in distilled water. The whole electrolysis process was carried out for 24 minutes in open atmosphere [14]:

- Volume of water taken in H_2 chamber of electrolyzer=45ml
- Volume of water taken in O_2 chamber of electrolyzer=45ml
- Instrument used for ion chromatography: ion chromatography metrohm (930 compact ic,switzerland)
- Column used: Metrosep C4 (for cation) and Metrosep A Supp.5 (for anion)

Sample 1: ultra-pure water (type 1)

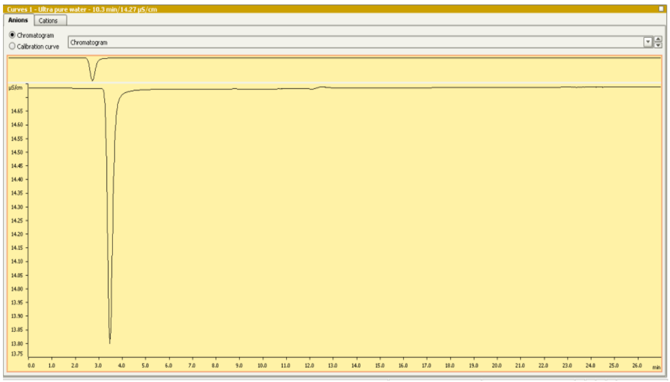


Figure 7: Anion test

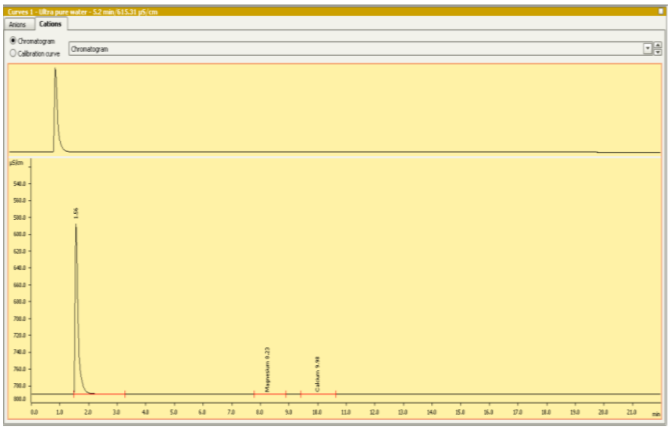
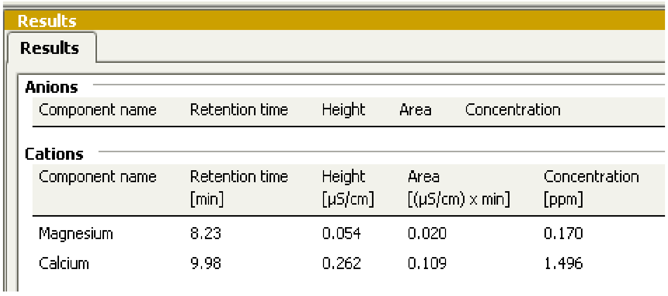


Figure 8: Cation test



Results

Anions

Component name	Retention time	Height	Area	Concentration

Cations

Component name	Retention time [min]	Height [µS/cm]	Area [(µS/cm) x min]	Concentration [ppm]
Magnesium	8.23	0.054	0.020	0.170
Calcium	9.98	0.262	0.109	1.496

Figure 9: Concentration of various ions

Sample 2:H_2 chamber water

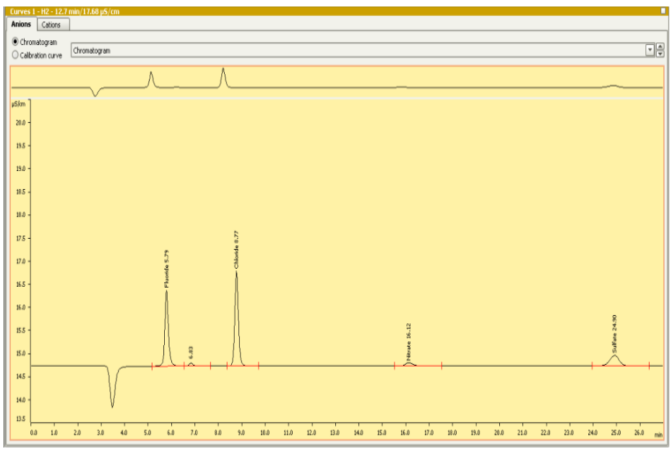


Figure 10: Anion test

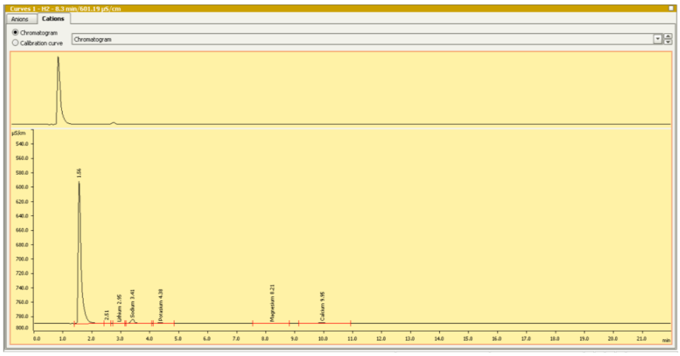


Figure 11: Cation test

Results				
Anions				
Component name	Retention time [min]	Height [µS/cm]	Area [(µS/cm) x min]	Concentration [ppm]
Fluoride	5.79	1.649	0.291	1.366
Chloride	8.77	2.058	0.368	2.372
Nitrate	16.12	0.071	0.027	0.803
Sulfate	24.90	0.226	0.107	1.057
Cations				
Component name	Retention time [min]	Height [µS/cm]	Area [(µS/cm) x min]	Concentration [ppm]
Lithium	2.95	0.013	0.003	0.031
Sodium	3.41	5.638	0.840	2.869
Potasium	4.38	0.859	0.184	1.255
Magnesium	8.21	0.214	0.077	0.282
Calcium	9.95	0.730	0.312	2.133

Figure 12: Concentration of various ions

Sample 3:O_2 chamber water

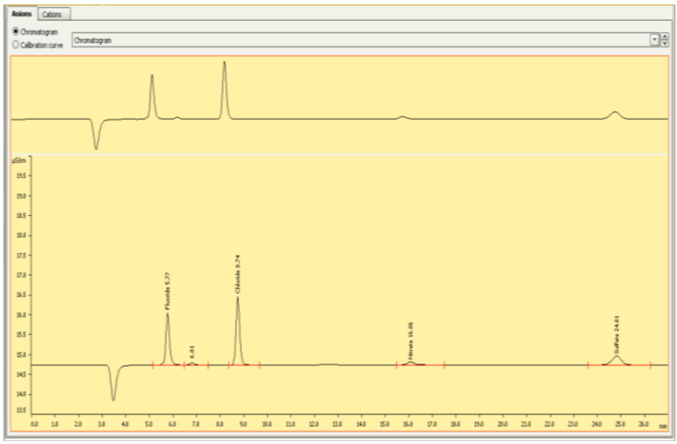


Figure 13: Anion test

Figure 14: Cation test

Results				
Anions				
Component name	Retention time [min]	Height [µS/cm]	Area [(µS/cm) x min]	Concentration [ppm]
Fluoride	5.77	1.329	0.238	1.215
Chloride	8.74	1.737	0.311	2.137
Nitrate	16.06	0.077	0.029	0.822
Sulfate	24.81	0.225	0.109	1.067
Cations				
Component name	Retention time [min]	Height [µS/cm]	Area [(µS/cm) x min]	Concentration [ppm]
Sodium	3.40	2.889	0.378	1.376
Potasium	4.38	0.667	0.144	1.067
Magnesium	8.23	0.230	0.083	0.294
Calcium	9.94	0.696	0.304	2.108

Figure 15: Concentration of various ions

V. INFERENCE

It was observed that 30 minutes of electrolysis has brought a blackish deposition at oxygen chamber side. We have conducted pH test for water in oxygen and hydrogen chamber and studied it with reference to the pH of distilled water.

It was observed that the pH of oxygen chamber is less than the distilled water used. It indicates that the water in oxygen chamber is becoming acidic.to ensure this we have taken two reading of pH for water stored in oxygen chamber each after 30 minutes of electrolysis process in open atmosphere.

Since we have use solar PEM electrolyzer the reaction undergoing for the formation of hydrogen and oxygen is

Anode: $H_2O \rightarrow 1/2O_2 + 2H^+ + 2e-$

Cathode: $2H^+ + 2e- \rightarrow H_2$

Taking in consideration, the reaction at anode side the oxidation of water takes place.as a result of this oxygen is liberated. From anode half reaction it is quite visible that as the reaction occurs hydrogen ion concentration near anode goes on increasing. As the concentration of hydrogen or better to say hydronium ion near anode is increasing, the acidic behavior near anode chamber will also increase. This fact is well established with the result obtained in pH test for first 30 min of electrolysis in open air, average pH in oxygen chamber came out be 7.25 and for next 30 min the result came out be 7.11.

This indicates that the oxygen chamber side is becoming acidic and this acidic behavior increases as the electrolysis is continued.

So, first inference made

1.pH of oxygen chamber will decrease indicating development of acidic behavior in oxygen chamber side.

Now the appearance of blackish deposition in oxygen chamber was the major observation:

For this we have performed ion chromatography test of the water left in oxygen chamber and hydrogen chamber after 24 min electrolysis in open air. This test was basically conducted to determine how the open atmosphere is affected the process of electrolysis. As air impurities cannot be neglected as the process is occurring open atmosphere ,it becomes necessary to estimate how much air impurity is interacting with water in electrolyzer.Type1 ultra-pure water was used to eliminate the effect of pre presence of ion in water sample.45ml of water sample was tested in ion chromatography metrohm device and the concentration of various cation and anion in ppm was evaluated. The result shown an unexpected result as the ion coming in the sample due to external environmental factor was quite appreciable in terms of concentration. The anion that came out where

- Fluoride
- Chloride
- Nitrate
- Sulphate

While cation that came out was

- Sodium
- Potassium
- Magnesium
- Calcium

As the whole process is carried at temperature around 38, the hydrogen H_2 will remain as inert and do not undergo any reaction.

While the oxygen gas produced will react with the air impurities constituting various ions which is further supported because of increase in acidic behavior in oxygen chamber. Formation of various oxides takes place

$$2\,Ca + O_2 \rightarrow 2\,CaO$$

$$2\,Mg + O_2 \rightarrow 2MgO$$

$$4\,Na + O_2 \rightarrow 2\,Na_2O$$

$$4K + O_2 \rightarrow 2K_2O$$

Now as the metallic oxide is basic in nature and the water in oxygen chamber has become slightly acid, it will facilitate the formation of salt.

Base + Acid → salt + water

This formation of salt formation leads to the appearance of blackish deposition. As the reaction depends upon the strength of acid means acidic nature of oxygen chamber, the increase in acidic behavior of chamber will leads to more deposition of blackish matter.

Various metallic oxide is being formed. Also, there is presence of various Sulphur and nitrate ion presence in the water which are the major constituent of air pollution.

The blackish deposition in oxygen chamber is because of the formation of various metallic oxide. As the oxygen is passed to fuel cell, along with oxygen various other oxides like sulphate, nitrate and metallic oxide also passed to fuel cell's oxygen side chamber.

So, second inference drawn from observation is

As oxygen side of electrolyzer is becoming acidic and the interaction of environmental components interaction with electrolyzer, formation of various metallic and nonmetallic oxide takes place. Because of this a blackish deposition in oxygen chamber of electrolyzer was obtained.

Now another thing we have observed that as the process was continued the speed with which the motor in load box was running becomes a bit slow. Also the output supplied by the fuel cell to the load box decreased a bit. This was also a major observation. This observation is explained by the formation of various oxides formed due to above.

When oxygen and hydrogen is passed to fuel cell two important reaction takes place

- oxygen reduction reaction
- Hydrogen oxidation reaction

PEM fuel cell are made up of assembly of membrane electrode which include electrode, electrolyte, catalyst, gas diffusion layer. A stream of hydrogen is passed through the anode side of fuel cell which causes oxidation of hydrogen producing electron and proton. This oxidation half-cell reaction or hydrogen oxidation reaction (HOR).

$$H2 \longrightarrow 2\,H+ + 2\,e-$$

The proton or hydrogen ion passes through the polymer electrolyte membrane which is a semipermeable membrane mostly made from ionomers that conduct protons while acting as an electronic insulator and reactant barrier to the cathode side. The electrons travel along an load circuit to the cathode side of the fuel cell, giving the current output of the fuel cell. A stream of oxygen is delivered to the cathode side of the fuel cell. At the cathode side oxygen molecules react with the protons/hydrogen ion passing through the polymer electrolyte membrane and the electrons arriving through the load circuit to form water molecules. This reduction half-cell reaction or oxygen reduction reaction (ORR).

$$O2 + 4\,e- + 4\,H+ \longrightarrow 2\,H2O$$

The catalyst which is platinum provides the surface for adsorption of hydrogen and oxygen gases.it is clear that whole process is facilitated by the catalyst which provides the surface for the adsorption of hydrogen and oxygen. More the amount of adsorbed hydrogen and oxygen more the output given by fuel cell.

But when impure oxygen is passed, some of the catalytic site is occupied by those impurities which reduces the site for oxygen, thus affect the ORR, hence the output provided by the fuel cell. In the presence of SO2 in the oxygen stream, the fuel cell current density dropped by over 50%.SO2also strongly adsorb on the Pt catalyst. The adsorption of S-containing species to the active sites of a catalyst, occupying the poly-atomic sites, prevented the reactants, including oxygen and hydrogen, from adsorbing at the catalyst surface. The cationic ions such as alkali metals, alkaline earth metals, transition metals, and rare earth metals were reported to directly affect the transport properties of the electrolyte membrane.[15]

So, the third inference made from observation

3.as the oxides of various cations and metal ions are passed along with oxygen to the fuel cell, drop in cell output is observed. Some of the active sites of catalyst is now occupied by the impurities coming along with oxygen, that interrupts HOR and ORR reaction. As the reaction is affected overall output of fuel cell is reduced thus a drop in motor speed of load box was observed.

The above observation also gives an idea about electrolyzer designing and fuel cell operation

Anode: $H_2O \rightarrow 1/2O_2 + 2H^+ + 2e-$

Cathode: $2H^+ + 2e- \rightarrow H_2$

Taking in consideration both half reactions, we can find that reaction at anode half is producing hydrogen ion along with oxygen gas while reaction at cathode side is yielding hydrogen gas. Taking in consideration mole as the basic unit it is quite visible that 1 mole of water yields 1/2 mole of oxygen gas and 2 moles of hydrogen ion. Thus, the amount of hydrogen ion produced will twice the concentration of water taken. A pH change is observed in the anode half chamber. We know that PH is defined as logarithmic value of concentration of hydrogen ion.

PH=-log [H+]

pH value obtained after 30 minutes of electrolysis is 7.25 and after furthermore 30 minutes of electrolysis is 7.11. Concentration of hydrogen ion generated can easily be evaluated.

FOR FIRST 30 Minutes [H+] =antilog(-PH) = antilog (-7.25) $=5.62\times10^{-8}$M

FOR NEXT 30 Minutes [H+] =antilog(-PH) = antilog (-7.11) $=7.76\times10^{-8}$M

Total time interval=30 minutes

Hydrogen ion produced$=7.76\times10^{-8} - 5.62\times10^{-8}= 2.14\times10^{-8}$M

Thus 2.14×10^{-8} moles of hydrogen ion per liter of hydrogen is produced in 30 minutes. We have taken 45ml of water sample thus total moles of hydrogen produced in 30 minutes

$$= 2.14\times10^{-8}\times45\times10^{-3} = 96.3\times10^{-11}\text{moles.}$$

Thus, it can be noted that the production of hydrogen ion depends on the volume of water used or better to say the size of electrolyzer. More the size of electrolyzer, more will be the hydrogen ion formed. This will cause a more drop in pH means the oxygen chamber will be more acidic if the size of electrolyzer is more. As the oxides of ions which are responsible for the blackish deposition, also depend on the acidic behavior and oxygen gas liberated of chamber formed, an increase in size will cause an increase in formation of blackish deposition. This metal oxide when passed along with oxygen in fuel cell, it causes a drop in output of fuel cell. As the blackish deposition increases more metal oxide will get passed in fuel cell, thus reducing the output of fuel cell to greater extent.

Thus, increase in PH of oxygen chamber not only affect electrolyzer performance but also the functioning of fuel cell. Another inference that can be made is

4. The concentration of hydrogen ion generated or PH of oxygen chamber depends upon the size of electrolyzer. More the size, more will be the decrease in PH of oxygen chamber. As pH is decreased, the formation of blackish deposition will facilitate in acidic condition. This blackish deposition, when get passed to fuel cell a significant drop is observed in fuel cell's output. Thus, designing of fuel cell is also an important parameter for fuel cell operation.

VI. CONCLUSION

From inferences made from the observation, it can be concluded that as the electrolysis of water takes place in electrolyzer a difference of pH is observed in hydrogen and oxygen chamber. Oxygen chamber of electrolyzer shown a acid behavior due to formation of hydrogen ion along with oxygen gas. As the electrolyzer is open to atmosphere various ions and impurities present of air interacts with the water present in electrolyzer. As the oxygen side has become slight acidic, interaction of these impurities leads to blackish deposition in the oxygen chamber. Various ions and impurities from air interact with the oxygen chamber and oxides of anions and cations gets formed. This leads to the deposition of a blackish matter in chamber. When oxygen and hydrogen is passed to fuel cell, some impurity along with oxygen is passed into fuel cell. These impurities occupy the active site of catalyst and reduces the output of fuel cell. The calculations made above provides an estimate of change in concentration of hydrogen ion for 30 minutes of operation. This calculation provides an idea about the drop in pH or increase in acidic nature of water in oxygen chamber if the process is continued for more time interval. The production of blackish deposition and its relative chance to get introduced in fuel cell increase in proportional to increase in acidic behavior. Thus, an estimate of the change in fuel cell output can also be made.

The data also provides an idea for electrolyzer designing at large scale. The observation made at small scale can act as a building block if electrolyzer is implemented at large scale. As fuel cell output also gets affected by improper operation of electrolyzer, the above results can also help in enhancing fuel cell output. Thus, the inference made can be implemented during set up of a large scale solar fuel cell power generation system.

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