



Sudan University of Science and Technology

College of Engineering

School of Electrical and Nuclear Engineering



Extraction Hydrogen from Water

استخلاص الهيدروجين من الماء

**A Project Submitted In Partial Fulfillment for the Requirements of
the Degree of B.Sc. (Honor) In Electrical Engineering**

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الاية

قال تعالى:

بسم الله الرحمن الرحيم

(لَكِنَّ الرَّاسِخُونَ فِي الْعِلْمِ مِنْهُمْ وَالْمُؤْمِنُونَ يُؤْمِنُونَ بِمَا أُنزِلَ إِلَيْكَ وَمَا أُنزِلَ مِنْ قَبْلِكَ ۗ

وَالْمُقِيمِينَ الصَّلَاةَ ۗ وَالْمُؤْتُونَ الزَّكَاةَ وَالْمُؤْمِنُونَ بِاللَّهِ وَالْيَوْمِ الْآخِرِ أُولَٰئِكَ سَنُؤْتِيهِمْ أَجْرًا

عَظِيمًا)

صدق الله العظيم

سورة النساء الآية (162)

الاهـ_____داء

بسم الله ابدؤها تحياتي

الى أمي الى محبوبتي انتي

الى ذاتي

الى من قلبها بالنور يغمري

ويأمرني بأن أتلو من القرآن آيات

لتنسيني حكاياتي وآلامي وآهاتي

وتجعلني سعيدا كل اوقاتي

إلى من أظهروا لي ما هو أجمل من الحياة إخوتي

إلى من كانوا ملاذي وملجني

إلى من تذوقت معهم أجمل اللحظات

إلى من جعلهم الله أخوتي بالله و من أحببتهم بالله طلاب قسم الكهرباء

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ABSTRACT

Hydrogen has the ability to burn quite fast so it was a good idea to use it as a fuel to generate electricity and we can get a handle on hydrogen from water analysis electrically. Here in Sudan we have the river Nile so it's easy to get water hence, gaining hydrogen from water and using it as a fuel is more inexpensive instead of using petroleum products . In addition, hydroxyl gas improves the quality of the fuel burning inside the engine, increases the engine power, cleans old carbon deposits off the inside of an old engine, and reduces the unwanted exhaust emissions. What we don't realize is that the ordinary fuel used in the engine is a "hydrocarbon" which is a compound of hydrogen and carbon and that fuel actually splits up to form hydrogen, which the engine burns. Actually, it is the carbon part of the hydrocarbon fuel which is the problem, producing Carbon Dioxide, Carbon Monoxide, and physical carbon deposits inside the engine.

The whole system consists of electrolyzers where the water gets analyzed and its connected to a generator. The gas is meant to be in combustion chamber of the generator to get burned and to move the shaft to start generation of electricity . The electrolyser consists of 8 cells each cell has a cathode and an anode rod which is made of aluminum or steel . They supply by direct current low voltage high current it should be at least 2 voltage per cell. The electrolyte is a mix of water and either NAOH or KOH to allow more current to flow through the liquid and they 25% to 30% of water weight. We figured that each liter of water produces about 1,750 liters of hydroxy gas.

The study intends to promote the possibility of using hydrogen in electric power. The motivation for using hydrogen for electricity generation is derived from the fact that the electric power sector is the greatest contributor to green house emissions. This problem of emissions must be addressed immediately. Hydrogen server the purpose as a source of clean energy and it's a friend of the environment.

المستخلص

إن للهيدروجين القدرة على الاحتراق سريعة للغاية و إنها فكرة جيدة لاستخدامه كوقود لتوليد الكهرباء ويمكننا الحصول على الهيدروجين من تحليل الماء كهربائياً. هنا في السودان لدينا نهر النيل لذلك فمن السهل للحصول على المياه وبالتالي، والحصول عليه من المياه واستخدامه كوقود هو أقل تكلفة بدلاً من استخدام المنتجات البترولية. وبالإضافة إلى ذلك، الغاز الهيدروكسيل يحسن نوعية حرق الوقود داخل المحرك، ويزيد من قوة المحرك، وينظف رواسب الكربون القديمة من الداخل للمحرك القديم، ويقلل من انبعاثات العادم غير المرغوب فيها. ما لا يدركونه هو أن الوقود العادي المستخدم في المحرك هو "النفط والغاز" الذي هو مركب من الهيدروجين والكربون والذي منه يتشكل الهيدروجين، الذي يحرقه المحرك. في الواقع، جزء الكربون من الوقود الهيدروكربوني، وإنتاج ثاني أكسيد الكربون وأول أكسيد الكربون، ورواسب الكربون المادية داخل المحرك تمثل المشكل .

ويتكون النظام برمته من الخلية التي يحصل فيها تحليل المياه والتي يتم توصيلها للمولد؛ حيث يدخل الغاز في غرفة الاحتراق و يحرق و منها يتحرك العضو الدوار لتوليد الكهرباء. تتكون الخلية من 8 خلايا كل خلية لديها الكاثود و أنود مصنوعين من الألومنيوم أو الفولاذ. يتم توصيلهم عن طريق مصدر تيار مباشر ذو جهد منخفض وتيار مرتفع؛ يجب ان تحصل كل خلية على 2 جهد مباشر. بالنسبة للمحول بداخل الخلية هو عبارة عن مزيج من الماء وإما هيدروكسيد الصوديوم أو هيدروكسيد البوتاسيم لتحفيز عملية التحليل ويكونون بسبة 25% إلى 30% من وزن ماء. برز لنا أن كل لتر من الماء تنتج نحو 1750 لتر من الغاز هيدروكسي.

تعتزم دراسة لتعزيز إمكانية استخدام الهيدروجين في توليد الطاقة الكهربائية. مع العلم أن قطاع الطاقة الكهربائية هو أكبر مساهم في انبعاثات الاحتباس الحراري. ويجب معالجة هذه المشكلة من الانبعاثات على الفور. الهيدروجين يعتبر كمصدر للطاقة النظيفة وانه صديق للبيئة.

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LIST OF SYMBOLS

CO	Carbon Monoxide
CO ₂	Carbon Dioxide
CH ₄	Methane
HHO	Hydroxy Gas
H ₂ O	Water
KOH	Potassium hydroxide
NaOH	Sodium hydroxide
I	Iodine
P	Resistivity
R	Resistance of the plate
L	The length of the plate
A	The area of the plate
COSØ	Power Factor

LIST OF ABBREVIATIONS

SMR	steam methane reforming
POX	Partial oxidation
ATR	Autothermal reforming
C.B	Circuit Breaker
e	Electron
PEM	Polymer electrolyte membrane
SOEC	Solid oxide electrolyzer cell
PV	Photovoltaic
DC	Direct Current
AC	Alternating Current

CHAPTER ONE

INTRODUCTION

1.1 Background

In the recent years, there has been a lot of interest in examining clean energy options. It is now recognized that our energy solutions must include a combination of various technologies integrated with energy storage and smart grid approaches. Even now, our energy comes mainly from fossil fuels like coal, oil and natural gas. The electric power sector is still largely dependent on fossil- fuel-based model.

The growing concerns regarding climate change have necessitated implementation of norms for mitigating greenhouse gas emissions. The electric power sector is the most important contributor to emissions. There is urgent need to change the existing system of electricity generation to make use of clean, renewable energy sources. But this change cannot take place all of a sudden. There must be a steady, gradual change of the methods.

Hydrogen derived from renewable sources is a clean energy resource. Burning it produces only water. Using hydrogen as transportation fuel and for distributed power generation in fuel cells is already being studied and in some places implemented. Hydrogen can also be used for utility scale electricity generation in power plants to mitigate emissions. This study is concerned with the feasibility of using hydrogen for large-scale electricity generation in power plants.

A renewable resource assessment in United States is made to know the potential for hydrogen production. Then, various methods of hydrogen

production, handling and delivery are studied. The use of hydrogen as a fuel in turbines is also studied along with some strategies that can be employed to make the model realizable in the near future.

Overall, the results of the study give a positive indication that hydrogen can be made use of in the electric power sector. The consequences will be highly beneficial not only to mitigate the emissions problem but also to encourage the utilization of more renewable resources to product hydrogen

1.2 State of problem

It is clear that Sudan depends on hydropower for electricity production , and this dependence is a danger in the future as to agreements of Nile basin countries and increasing investment in agricultural projects and it hasn't high stability . Hence, there must be other sources to generate electricity to meet the shortfall in the growing energy demand. Also highly cost and magnitude of fuel used to operate boiler and super heater. The hydroxy gas improves the quality of the fuel burn inside the engine, increases the engine power, cleans old carbon deposits off the inside of an old engine, reduces the unwanted exhaust emissions.

Burning hydroxy (hydrogen/oxygen mix) gas produces water and they imagine this water causing rusting inside the engine. What they don't realise is that the ordinary fuel used in the engine is a "hydrocarbon" which is a compound of hydrogen and carbon and that fuel actually splits up to form hydrogen which the engine burns. Actually, it is the carbon part of the hydrocarbon fuel which is the problem, producing Carbon Dioxide, Carbon Monoxide, and physical carbon deposits inside the engine. A normal fuel

burn produces water anyway, but you don't get rusting inside the engine as the temperature there is so high that any water is in the form of steam or vapour which dry out completely when the engine is switched off. Adding a small amount of hydroxy gas has no adverse effects at all.

1.3 Objectives

The main of the research summarized as follow:

- design the electrolyzer.
- find the source of the cell.
- produce electricity form hydroxy gas.

1.4 Methodology:

The cell will be designed and built actually to obtain the required data of a study .Then the protective scheme will designed such as bubblers and C.B.

1.5 Project lay-out

The project is organized as follow:- Chapter one: - summarized research problem and objectives, also it give brief introduction about renewable and conventional energy. Chapter two: - this chapter illustrates Generation of hydroxy gas and effected factors. Chapter three:- The theory of producing hydrogen and the generator plant. Chapter four:- This chapter consist the unit design of hydroxy and the modulation. Chapter five:- this chapter shows the conclusion and recommendations.

CHAPTER TWO

LETTRITURE REVIEW

2.1 Introduction

The technologies discussed are reforming of natural gas; gasification of coal and biomass; and the splitting of water by water-electrolysis, photo-electrolysis, photo-biological production and high temperature decomposition. For all hydrogen production processes, there is a need for significant improvement in plant efficiencies, for reduced capital costs and for better reliability and operating flexibility.

Water electrolysis and natural gas reforming are the technologies of choice in the current and near term. They are proven technologies that can be used in the early phases of building a hydrogen infrastructure for the transport sector. Small-scale natural gas reformers have only limited commercial availability, but several units are being tested in demonstration projects. In the medium to long term, centralised fossil fuel-based production of hydrogen, with the capture and storage of CO₂, could be the technology of choice. However, the capture and storage of CO₂ is not yet technically and commercially proven.

The production of hydrogen from biomass needs additional focus on the preparation and logistics of the feed, and such production will probably only be economical at a larger scale. Photo-electrolysis is at an early stage of development, and material costs and practical issues have yet to be solved. The photo-biological processes are at a very early stage of development with only low conversion efficiencies obtained so far. High-

temperature processes need further materials development that focuses on high temperature membranes and heat exchangers.

2.2 History of project

- 1766 Everything began when Henry Cavendish, British scientist, discovered something he called “inflammable air”. He defined and described, for the very first time, the density of this inflammable air, created by water during combustion, in a newspaper article.
- 1776 Dutch scientist Martinus van Marus (1750-1837) during one of his experiment with electricity created oxygen and gaseous hydrogen with the help of electrolysis. He discovered, maybe by accident, that this mixture could be inflamed with an electric spark.
- 1789 Dutch chemists Paets van Troostwijk and Joan Rudolph Deiman were the first to define in their experiments that water consists of two elements, 1 molecule of oxygen O and 2 molecules of hydrogen H₂, which can be separated by electric current.
- Francois Isaac de Rivaz (1752-1828), Swiss inventor, was first to successfully create a combustion engine. This engine was fueled by a mixture of hydrogen and oxygen. A year later, he was successful in building one of the first automobiles, which was, of course, powered by his new hydrogen engine. During these times this was monumental technological advance. NOTE: First gasoline powered engine was not used until 1870.
- 1860 Belgian and French Jean Bienne Lenoir designed and constructed automobile, in which he also used an engine that produced hydrogen with the help of electrolysis. It ran on an electric battery.
- 1875 Writer and a visionary Jules Verne wrote the following sentence in

his book *The Mysterious Island*: „Water will decompose into its primitive elements and will be decomposed doubtless by electricity, which will then become a powerful and manageable force. Yes, my friends, I believe that water will one day be employed as fuel.”

- 1888 Especially in the last years of 19th century a number of experiments were performed concerning the production of hydrogen gas. They were, for example, addition of hydrogen vapour into hydrogen flame to improve its flammability for lighting and heating purposes, or safe burning of hydrogen mixed with oxygen in Bunsen burner and the use of mesh screen for safety. Even during these times, they clearly knew how to use this gas but it was not economical thanks to the high price of electricity (used for creating hydrogen) and its limited accessibility.

- 1918 Charles H. Frazer patented first hydrogen generating cell (Hydrogen Booster) for combustion engines in the US. (USA Patent.No. 1262034). He cited that his invention increases the effectivity of combustion engines, completely burns hydrocarbons, the engine gets cleaner and even more important, that a lower amount of fuel can be used, along with fuel of lower quality to achieve the same performance. Most likely this is when the history of HHO generators, as we know them today, began to be written.

- 1935 Henry Garrett, talented American inventor from Dallas, along with his son patented an automobile that ran on water. In reality it was a mixture of hydrogen and oxygen converted from water by electrolysis. Today this mixture is known as HHO.

- 1943 Thanks to the serious shortage of conventional fuel at the end of the Second World War (WW2) the British army used HHO Oxyhydrogen gas generators in their tanks, boats and other automobiles to increase their range

and protect the engines from overheating in Africa. They used generators very similar to those that save fuel thanks to HHO today. Immediately after WW2 the government has ordered the destruction of all of these generators from all of the automobiles and tanks.

- William A. Rhodes (USA) is the first inventor of the well-known patent on electrolyser which produced easily removable gas, known today as HHO. In the mid 1960s Rhodes along with his partners founded the Henes Corporation which started to sell the electrolysers commercially.

- Few years after William Rhodes, the Australian Yull Brown (Bulgarian, born Ilja Velbov 1922-1998) patents his own construction of gas electrolyser (known today as Brown electrolyser after this inventor). Brown has spent big part of his life trying to commercialise his device. He successfully persuaded investors to invest \$30M into further development and marketing of his device and his dream of commercial success began to blossom. His investors lasted almost 30 years. Because of his lifelong quest and work he was honored by the world and we now know this mixture of hydrogen (water H₂O split into its individual molecules H-H-O in the ration of 66 parts of hydrogen to 34 parts of oxygen) as Brown's gas.

- Many companies were later funded as both collaborators and competition with Yull Brown.

- In the second half of 1970s one German company began producing oxyhydrogen generator in large quantities. They have used new materials and parts, but have still kept the Brown's elements original, made out of massive steel, just as they would be were they used during WW2. As with all military equipment, these generators were created to be tough and have longevity and because of this, they are still functional today.

- NASA Lewis research center created a number of tests on typical American 8 cylinder engine (V8 LARGE BLOCK). The results were shocking. They

were also developing alternative method of gas production that would be more effective than the basic electrolysis.

- Juan Carlos Aquero patented system that converted energy for combustion engines using HHO gas and vapor. (European patent: 0 405 919 A1/90306988.8 26-26-1990)

- The same year an inventor from the US and most likely the biggest pioneer of the modern HHO technology, Stanley A. Meyer, was granted a patent for a method of production of oxyhydrogen fuel gas (Oxygen-Hydrogen Fuel Gas) (USA Patent number : 4936961). What he has achieved and what was really ground breaking was the dielectric resonant circuit. Stanley Meyer created a car which used water as its fuel source.

- 1991 Kim Sang Nam from Korea visited the laboratory of Yull Brown in Sidney, Australia. This was the beginning of Brown's collaboration with big Korean corporation focused on HHO technologies. They were successful in developing innovative technology involving Brown's gas. Today, thanks to this corporation, Korea is a major manufacturer of the original Brown's gas generators. In this country, the HHO technologies are becoming more and more popular in recent years.

- During the next few years many other influential companies in many countries around the world started to research HHO and Brown's gas, including USA, Germany, Great Britain, France and others. In Canada, where these alternative fuel options are quite popular and also in recent

years on the upswing, some companies have abandoned the traditional technology and construction of electrolyzers and began with completely new concepts while keeping the ideas from the past research. They have improved on William Rhode's construction effectively and in an interesting way. Today there are many companies around the world selling generators of the Brown's type, HHO and others.

- 2000 Many companies around the world are beginning to patent their HHO generators. Korea has gone the furthest, where even the multinational Samsung is showing interest in this area. This technology is more and more popular in Asia and the rest of the world is quick to follow and catch up. In Europe and Great Britain first CE safety certificates were awarded to HHO devices used in combustion engines. In western and central Europe more and more companies are popping up, slowly entering the world market of alternative energies and HHO systems.

2.3 Hydrogen generation

Hydrogen can be produced from a variety of feedstocks. These include fossil resources, such as natural gas and coal, as well as renewable resources, such as biomass and water with input from renewable energy sources (e.g. sunlight, wind, wave or hydro-power). A variety of process technologies can be used, including chemical, biological, electrolytic, photolytic and thermo-chemical. Each technology is in a different stage of development, and each offers unique opportunities, benefits and challenges. Local availability of feedstock, the maturity of the technology, market applications and demand, policy issues, and costs will all influence the choice and timing of the various options for hydrogen production. An overview of the various feedstocks and process technologies is presented in

Figure 2.1

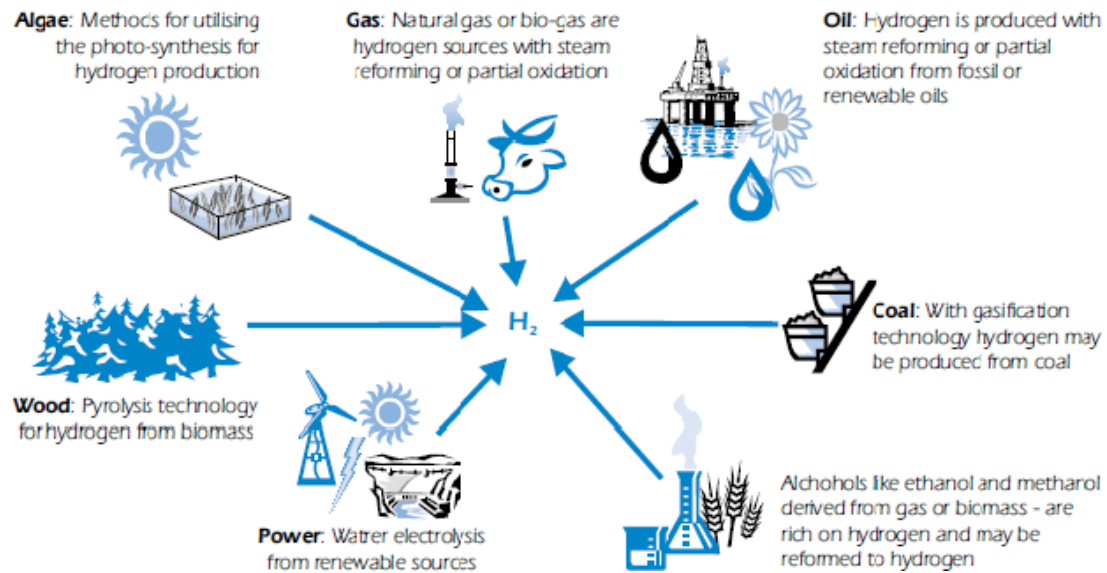


Figure 2.1: Some feedstock and process alternatives

The hydrogen can be product from fossil energy source, biomass, and from splitting of water.

2.3.1 From fossil energy source:-

Hydrogen can be produced from most fossil fuels. The complexity of the processes varies, and in this chapter hydrogen production from natural gas and coal is briefly discussed. Since carbon dioxide is produced as a by-product, the CO₂ should be captured to ensure a sustainable (zero-emission) process. The feasibility of the processes will vary with respect to a centralised or distributed production plant.

❖ Production from natural gas

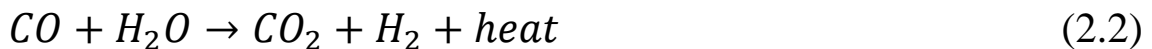
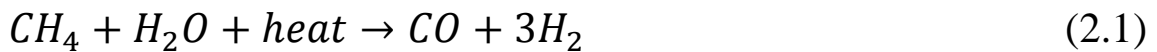
Hydrogen can currently be produced from natural gas by means of three different chemical processes:

- Steam reforming (steam methane reforming – SMR).

- Partial oxidation (POX).
- Autothermal reforming (ATR).

Although several new production concepts have been developed, none of them is close to commercialisation.

Steam reforming involves the endothermic conversion of methane and water vapour into hydrogen and carbon monoxide (2.1). The heat is often supplied from the combustion of some of the methane feed-gas. The process typically occurs at temperatures of 700 to 850 °C and pressures of 3 to 25 bar. The product gas contains approximately 12 % CO, which can be further converted to CO₂ and H₂ through the water-gas shift reaction (2.2).



Partial oxidation of natural gas is the process whereby hydrogen is produced through the partial combustion of methane with oxygen gas to yield carbon monoxide and hydrogen (2.3). In this process, heat is produced in an exothermic reaction, and hence a more compact design is possible as there is no need for any external heating of the reactor. The CO produced is further converted to H₂ as described in equation (2.2).



Auto thermal reforming is a combination of both steam reforming (2.1) and partial oxidation (2.3).

The total reaction is exothermic, and so it releases heat. The outlet temperature from the reactor is in the range of 950 to 1100 °C, and the gas pressure can be as high as 100 bar. Again, the CO produced is converted to

H₂ through the water- gas shift reaction (2.2). The need to purify the output gases adds significantly to plant costs and reduces the total efficiency.

❖ **Production from coal**

Hydrogen can be produced from coal through a variety of gasification processes (e.g. fixed bed, fluidised bed or entrained flow). In practice, high-temperature entrained flow processes are favoured to maximise carbon conversion to gas, thus avoiding the formation of significant amounts of char, tars and phenols. A typical reaction for the process is given in equation (2.4), in which carbon is converted to carbon monoxide and hydrogen.



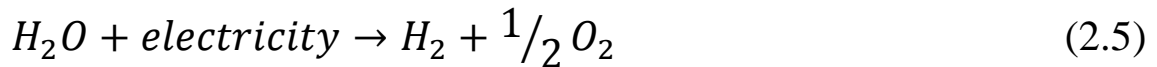
Since this reaction is endothermic, additional heat is required, as with methane reforming. The CO is further converted to CO₂ and H₂ through the water-gas shift reaction, described in equation (2.2). Hydrogen production from coal is commercially mature, but it is more complex than the production of hydrogen from natural gas. The cost of the resulting hydrogen is also higher. But since coal is plentiful in many parts of the world and will probably be used as an energy source regardless, it is worthwhile to explore the development of clean technologies for its use.

2.3.2 From splitting of water:-

Hydrogen can be produced from the splitting of water through various processes. This paper briefly discusses water electrolysis, photo-electrolysis, photo-biological production and high-temperature water decomposition.

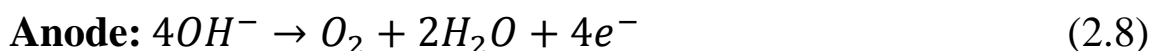
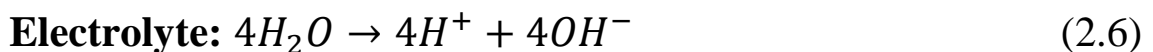
❖ Water electrolysis

Water electrolysis is the process whereby water is split into hydrogen and oxygen through the application of electrical energy, as in equation (2.1). The total energy that is needed for water electrolysis is increasing slightly with temperature, while the required electrical energy decreases. A high-temperature electrolysis process might, therefore, be preferable when high-temperature heat is available as waste heat from other processes. This is especially important globally, as most of the electricity produced is based on fossil energy sources with relatively low efficiencies.



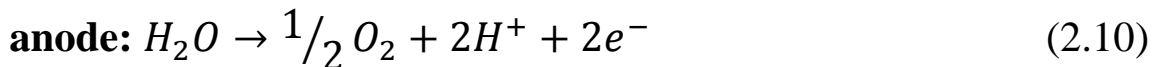
❖ Alkaline electrolysis

Alkaline electrolyzers use an aqueous KOH solution (caustic) as an electrolyte that usually circulates through the electrolytic cells. Alkaline electrolyzers are suited for stationary applications and are available at operating pressures up to 25 bar. Alkaline electrolysis is a mature technology, with a significant operating record in industrial applications, that allows remote operation. The following reactions take place inside the alkaline electrolysis cell:



❖ Polymer electrolyte membrane (PEM) electrolysis

The principle of PEM electrolysis is presented in equations (2.6) and (2.7). PEM electrolyzers require no liquid electrolyte, which simplifies the design significantly. The electrolyte is an acidic polymer membrane. PEM electrolyzers can potentially be designed for operating pressures up to several hundred bar, and are suited for both stationary and mobile applications. The main drawback of this technology is the limited lifetime of the membranes. The major advantages of PEM over alkaline electrolyzers are the higher turndown ratio⁵, the increased safety due to the absence of KOH electrolytes, a more compact design due to higher densities, and higher operating pressures.



With relatively high cost, low capacity, poor efficiency and short lifetimes, the PEM electrolyzers currently available are not as mature as alkaline electrolyzers. It is expected that the performance of PEM electrolyzers can be improved significantly by additional work in materials development and cell stack design.

❖ High-temperature electrolysis

High-temperature electrolysis is based on technology from high temperature fuel cells. The electrical energy needed to split water at 1000 °C is considerably less than electrolysis at 100 °C. This means that a high-temperature electrolyser can operate at significantly higher overall process

efficiencies than regular low- temperature electrolyzers. A typical technology is the solid oxide electrolyser cell (SOEC). This electrolyser is based on the solid oxide fuel cell (SOFC), which normally operates at 700 to 1000 °C. At these temperatures, the electrode reactions are more reversible, and the fuel cell reaction can more easily be reversed to an electrolysis reaction. Attempts are currently underway to develop systems in which some of the electricity consumed by the electrolyser can be replaced with the heat available from geothermal, solar or natural gas sources, thus reducing the consumption of electricity significantly.

❖ Photo-electrolysis (photolysis)

Photovoltaic (PV) systems coupled to electrolyzers are commercially available. The systems offer some flexibility, as the output can be electricity from photovoltaic cells or hydrogen from the electrolyser. Direct photo-electrolysis represents an advanced alternative to a PV-electrolysis system with conventional two-step technologies.

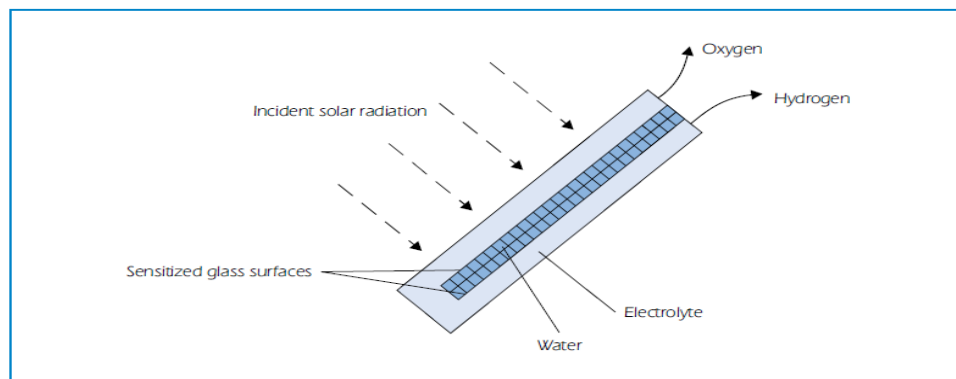


Figure 2.2 :Principle of photo-electrolytic cell

❖ Photo-biological production (biophotolysis)

Photo-biological production of hydrogen is based on two steps:

photosynthesis (2.8) and hydrogen production catalysed by hydrogenases (2.9) in, for example, green algae and cyanobacteria. Longterm basic and applied research is needed in this area, but if successful, a long-term solution for renewable hydrogen production will result. It is of vital importance to understand the natural processes and the genetic regulations of H₂ production. Metabolic and genetic engineering may be used to demonstrate the process in larger bioreactors. Another option is to reproduce the two steps using artificial photosynthesis.

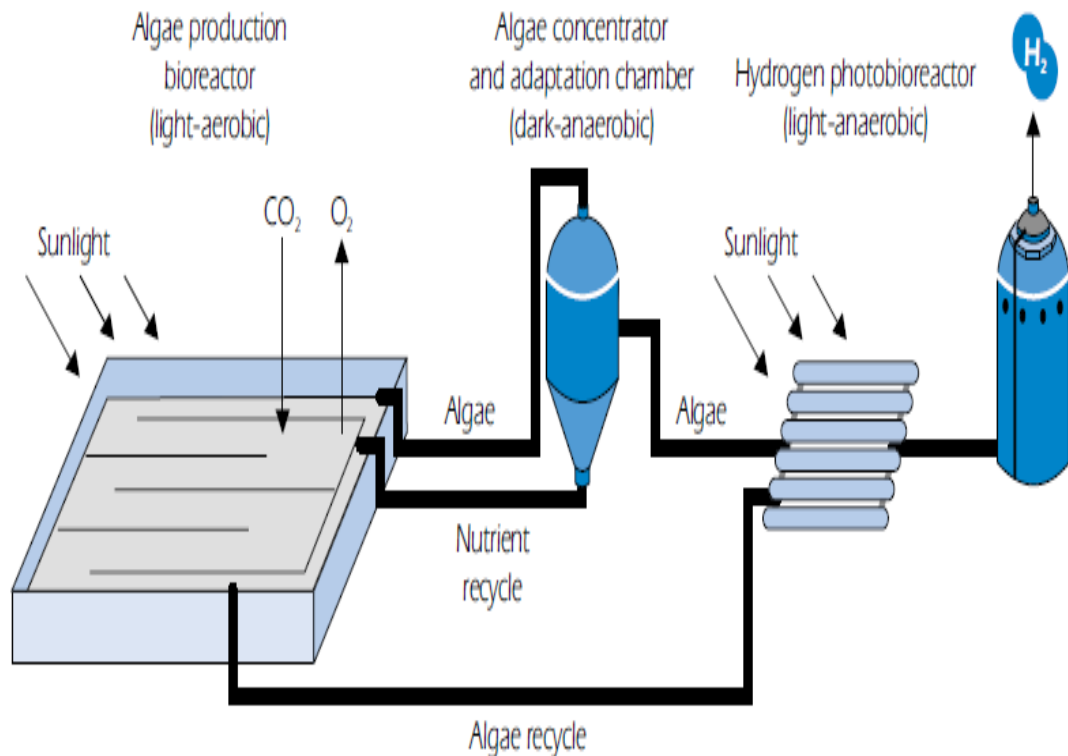
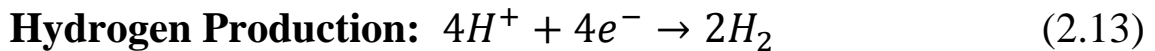
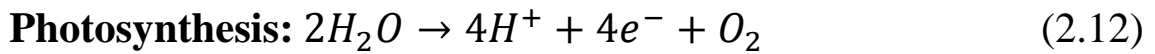


Figure2.3: Principle of photo-biological hydrogen production

❖ High-temperature decomposition

High-temperature splitting of water occurs at about 3000 °C. At this temperature, 10% of the water is decomposed and the remaining 90% can be recycled. To reduce the temperature, other processes for high temperature splitting of water have been suggested:

- Thermo-chemical cycles.
- Hybrid systems coupling thermal decomposition and electrolytic decomposition.
- Direct catalytic decomposition of water with separation via a ceramic membrane (“thermo-physic cycle”).
- Plasma-chemical decomposition of water in a double-stage CO₂ cycle.

For these processes, efficiencies above 50 % can be expected and could possibly lead to a major decrease of hydrogen production costs. The main technical issues for these high-temperature processes relate to materials development for corrosion resistance at high temperatures, high-temperature membrane and separation processes, heat exchangers, and heat storage media. Design aspects and safety are also important for high-temperature processes.

❖ Thermo-chemical water splitting

Thermo-chemical water splitting is the conversion of water into hydrogen and oxygen by a series of thermally driven chemical reactions. Thermo-chemical water-splitting cycles have been known for the past 35 years. They were extensively studied in the late 1970s and 1980s, but have been of little interest in the past 10 years. While there is no question about the

technical feasibility and development needs are to capture the thermally split H₂, to avoid side reactions and to eliminate the use of noxious substances. The corrosion problems associated with the handling of such materials are likely to be extremely serious.

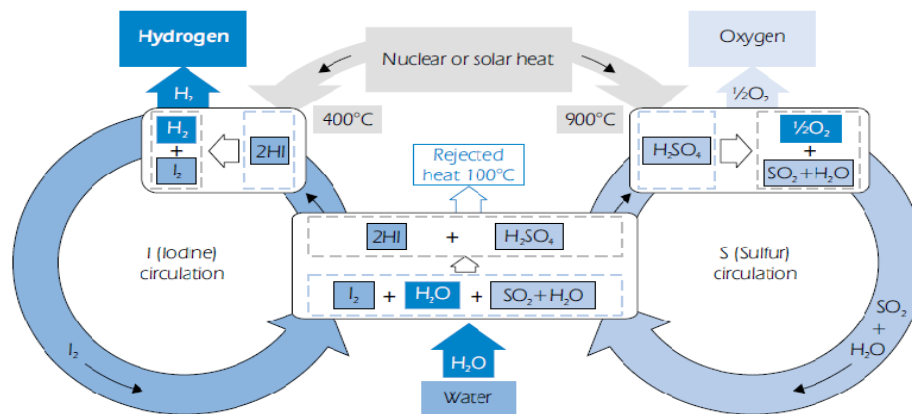
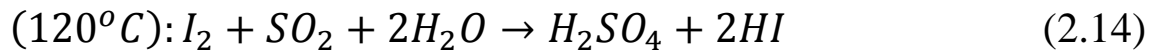
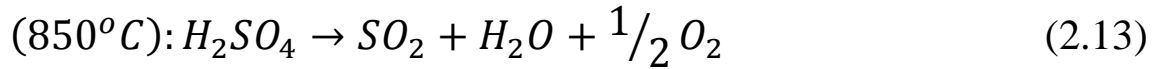


Figure 2.4: Principle drawing of iodine/sulfur thermo-chemical process

❖ Biomass to hydrogen

In biomass conversion processes, a hydrogen-containing gas is normally produced in a manner similar to the gasification of coal, as in equation (2.4). However, no commercial plants exist to produce hydrogen from biomass. Currently, the pathways followed are steam gasification (direct or indirect), entrained flow gasification, and more advanced concepts such as gasification in supercritical water, application of thermo-chemical cycles, or

the conversion of intermediates (e.g. ethanol, bio-oil or torrefied wood). None of the concepts have reached a demonstration phase for hydrogen production.

Biomass gasification is an R&D area shared between H₂ production and biofuels production. Gasification and pyrolysis are considered the most promising medium-term technologies for the commercialisation of H₂ production from biomass. A typical flow sheet for the production of hydrogen from biomass is presented in Figure 8. In terms of its energy requirements, the drying of biomass might not be justifiable; therefore, other pathways based on wet biomass are being sought as well.

Biomass feedstocks are unrefined products with inconsistent quality and poor quality control. The production methods vary according to crop type, location and climatic variations. Erratic fuels have contributed to the difficulties in technological innovation, since less homogenous and low-quality fuels need more sophisticated conversion systems. There is a need to rationalise the production and preparation of fuel to produce more consistent, higher-quality fuels that can be described by common standards. Large-scale systems tend to be suitable for cheaper and lower quality fuels, while smaller plants tend to require higher levels of fuel quality and better fuel homogeneity. A better understanding of this relationship, and the specific tolerances that each technology can accommodate, is needed.

Several developments are needed to improve the economics of production processes and the logistics of handling a biomass feedstock:

- Feed preparation and identifying the characteristics of feedstocks that will allow the technologies to develop.
- Gasification of biomass. This is not specific for hydrogen, but relates to

general biomass and renewables pathways and research.

- Raw gas handling and clean-up.
- Interface issues and system integration. One should also investigate the relationship between the production scale and the fuel quality requirements and tolerances that can be accommodated for the respective technologies.

2.4 Factors with an influence on electrical efficiency in water electrolysis:

2.4.1 Electrolyte quality

Bases and acids are known to change the nonconductive nature of pure water. These compounds have a great reducing effect on the overvoltage value of an electrolyzer due they improve the ionic conductivity aqueous electrolyte compounds. However, the concentration level of acidic and alkali solutions are limited in practice due to the highly corrosive behavior of such materials. A 25% to 30% KOH aqueous solution is reported to have a wide use in electrolyzers. On the other hand, the electrocatalytic performance of water electrolysis cell is known to be limited. This limitation is mainly cause the overall electrical resistance of a cell to rise and will cause the efficiency to fall. Therefore, substitute electrolytes such as ionic liquids have been introduced to improve the conductivity and stability factors of electrolytic baths. The electrode plates of these cases were selected from a number of easily found metals such as carbon steel, Nickel, Nickel-Molybdenum alloy and Molybdenum. A maximum efficiency value of 96% was reported for the case of low carbon steel electrodes in 10 vol.% aqueous solution of MBI.MF4. However, it should be considered that such electrolyzers usually function at much higher

current densities than the mentioned experimental value. Moreover, any existence of impurities may cause unwanted side reactions in an electrolysis cell. Magnesium, chloride and calcium ions can be named as a few common examples of these impurities. In addition, contaminations can block and passivate the electrode plates and/or separator surfaces and sabotage the inter-electrode mass and electron transfer. The latter-mentioned is another formation cause for the excess ohmic resistance of the electric current path.

2.4.2 Temperature

Temperature is known to be one of the most effective variables on the electric power demand of an electrolysis cell. Electrolysis process is much more efficient at raised temperatures. The reasons of this behavior can be discussed according to the thermodynamic characteristics of a water molecule, as its splitting reaction potential is known to reduce as the temperature increases. Moreover, ionic conductivity and surface reaction of an electrolyte rise directly with temperature. High temperature water electrolysis requires less energy to reach any given current density in analogy with a low temperature process.

2.4.3 Pressure

Appleby et al. tried to lower the costs of hydrogen production by creating higher current density conditions in conventional electrolyzers. According to their research, high pressure electrolytes will consume less power in the process of electrolytic decomposition. The main reason was stated to be the shrinking effect of pressure on the gas bubbles which cause the ohmic voltage drop and power dissipation to reduce. Moreover, high pressure electrolysis has less power demand for the phase of product compression. These experiments were conducted in a typical three compartment

electrolyzer with a varying temperature between 25°C and 90°C. Cell current density was kept at 1 mA cm⁻² with an electrolyte of either a 34%wt or 25%wt KOH solution in distilled water. The electrodes were chosen from pure platinum (99.99%) and smooth nickel (Ni 200) plates with a 1 cm² surface area. Authors noted an overall voltage drop of up to 100mV when the conversion process was conducted at a pressure level of under 30 atm. No significant further voltage drop was recorded at higher pressure values (up to 40 atm). The cell voltage vs pressure graph has its highest reduction slope when the pressure was raised from 1atm to 10atm despite of the process temperature. Referring to a similar work, Onda et al. calculated the energy consumption of compressing a liquid electrolyte to be much less than those of gas state hydrogen compression. These calculations were based on the results of an earlier research of LeRoy et al. They estimated the ideal temperature and pressure conditions for electrolytic hydrogen production to be around 70 MPa and 250 °C relatively. High temperature and intense pressure will change both Gibbs energy and enthalpy levels of an electrolysis process. Hence, lower voltage level will be required as the temperature rises in high pressures and vice versa. However, in pressure levels higher than 20MPa, they found the voltage rise to be negligible. This behavior became more sensible at lower temperatures. Finally, an electrolysis efficiency enhancement of 5% was observed. Another 50% of energy was saved at the compression phase of high pressure electrolytic hydrogen production.

2.4.4 Electrical resistance of the electrolyte

Electrical resistance of an object is an evaluation of its opposition to the passage of electric current. The level of this force is proportional to the

cross section area and the length of the current path and the material resistivity of the conducting material. The relationship between the mentioned variables is shown in equation as bellow.

$$R = \frac{\rho l}{A} \quad (2.17)$$

Where A is the cross section area, ρ is the material resistivity, R is the electrical resistance, and l is the length of the current path. Inside and electrolysis cell, electrons start their travel from the surface of an electrode, move through the electrolyte and end their journey at the surface of the other electrode. We can assume the path as an object with the same length as the distance between electrodes, the cross section of the area of electrodes overlap and an equivalent resistivity value. The equivalent resistivity consists of different variables such as the electrodes resistivity, electrical admittance of the electrolyte and the reaction between electrodes surfaces and electrolyte. Hence, the equivalent resistivity is a function of the following variables:

2.4.4.1 Space between the electrodes

According to equation (2.17), by reducing the distance between electrodes, lower electrical resistance can be obtained. larger electrical resistance of an electrolyte is a result of gas bubbles accumulation in the inter-electrode area. Therefore, this accumulation will cause the process to be less efficient.

2.4.4.2 Size and alignment of the electrodes

Another variable of equation 1 is the cross section area of an object. Less resistive current path is known to be a result of using electrodes with larger surface areas. Again, in this case, it would be useful to define the term “larger surface area” in more details. At the same electrode width, larger

electrode height will cause additional power dissipation in a cell. The reason was expressed to be the formation of a larger volume of void fraction. The models of gas bubbles movement clearly depict larger amounts of bubble accumulation in higher parts of the electrodes. Higher efficiency levels can be obtained by placing the electrodes in a vertical position.

2.4.4.3 Forcing the bubbles to leave

Ohmic resistance in an electrolysis bath is related to the bubble coverage of all surfaces since gas bubble accumulation on each surface will reduce its conductivity. Hence, it causes a higher level of ohmic voltage drop. On the other hand, bubbles diameter depends on the current density, temperature and pressure. Pressure value has an inverse correlation with the bubbles size where current density and temperature have an opposite affect it. Moreover, the disengagement rate of gas bubbles from the surfaces and their departure velocity play a significant rule in the value of the electrical resistance of an electrolytic bath. Figure 1 justifies this subject. In this figure, the distance between electrodes “ l ” is broken into n smaller segments “ l_i ”. Equation 4 can be used to calculate the resistance for each partial length of l_i . The presence of gas bubbles significantly reduces the efficient cross section area for each l_i . Therefore, it increases the total value of R .

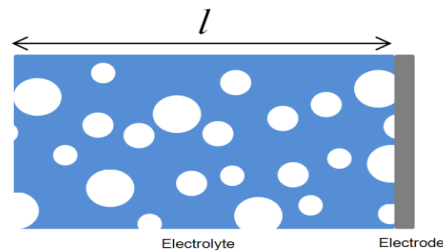


Figure2.5: The formation of void fraction

Hence, equation (2.17) could be re-written as bellow:

$$R = (\sum l_i) \quad (2.18)$$

Equation (2.18) and figure 2.5 depict the effect of void fracture which has been discussed earlier. Many efforts are made to force the bubbles leave the cell environment. Forcing the bubbles to disengage from electrodes, membrane and electrolyte surface is known to improve the local mass and heat transfer as well as the process efficiency. Power consumption of the ultrasonic generator is expressed to be negligible in contrast with the power demand of the cell itself.

2.4.5 Electrode material

A wide range of materials are being used as electrodes. Each metal has a different level of activity, electrical resistance and corrosion resistivity. Platinum and gold are known to be two of the best choices for being used as electrodes. However, high prices limit their usage in industrial and commercial electrolyzers. Aluminum, Nickel, Raney nickel and cobalt are the most common electrode materials for being used in alkaline electrolytic baths. This popularity is the result of their satisfactory price range, corrosion resistance and chemical stability. There is a wide range of variations in the value of electrode-electrolyte activity for different materials. For example, platinum electrodes show higher activity levels in contact with KOH aqueous solutions in comparison with molybdenum plates.

2.4.6 Separator material

Placing a separator plate in a cell, blocks the free movement of mass and ions to some extent. Moreover, the presence of such barrier increases the

void fracture by further accumulating of gas bubbles in the electrolyte. In addition, the effective electrical resistance of a separator plate is frequently calculated to be as large as three to five times of those of the electrolyte solutions. Electrical resistance of a separator depends on different variables such as corrosion, temperature and pressure. Back in middle 1990's many scientists named asbestos to be the best choice for being used as a diaphragm due to its highly wettable and porous structure. These features cause a plate to show electrical resistance in practice. However, asbestos is known to be a toxic and hazardous material. These characteristics caused the researchers to start looking for substitute materials. Nowadays there are different materials and technologies available to reduce the negative electrical effect of separators.

2.4.7 Applied voltage waveform

It is almost common for electrolysis systems to use a steady (Figure 2.6a) or smooth (Figure 2.6b) DC voltage to decompose an electrolyte.

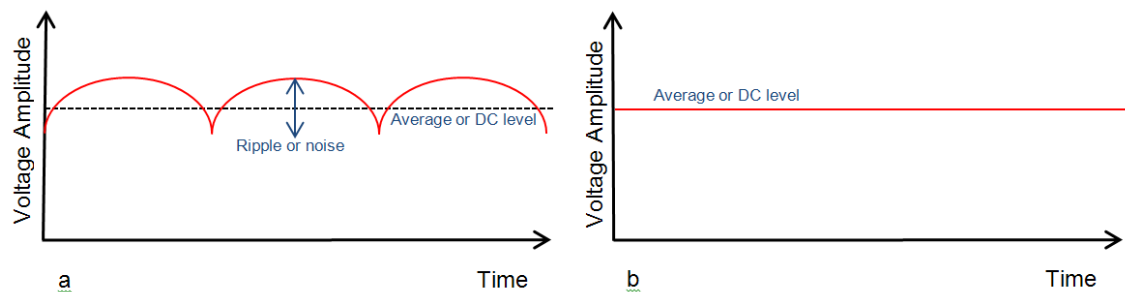


Figure 2.6: (a) Steady DC voltage waveform. (b) Smooth DC voltage waveforms. According to the Ohm's law, applied DC voltage V causes the current I to pass through the electrolyte with the resistance of R . Hence, the common method of current or current density regulation is by the

application of a certain voltage to a cell. The utilization of an ultra-short pulse generator provided the possibility of subjecting the cell to higher power levels without causing any further energy loss. The latter is achievable if the power is regulated by adjusting the peak pulse voltage levels. Moreover, raised pulse frequency can deliver extra power to the cell without causing any significant effect on the efficiency. The authors mentioned a lower electron energy level caused by sharper pulse waveforms to be the reason of this behavior.

CHAPTER THREE

HYDROGEN SYSTEM

3.1 Introduction

The main way of running an engine with water as the only fuel, involves splitting water into hydrogen and oxygen and then burning those gases to power the engine. To be self-sustaining, the splitting of the water has to be done by the electrics of the vehicle and that means that the efficiency of the water splitting has to be more than 200% efficient. Feeding a hydrogen/oxygen gas mix (called “hydroxy” gas) into engine along with the air which is drawn in to make the engine run. A device of this type is called a “booster” as it boosts the fuel burn, extracting a greater percentage of the fuel’s available energy. An important side effect of this improvement in the burn quality of the fuel is the fact that unburnt fuel no longer gets pushed out of the exhaust as harmful emissions. Another effect is that the engine has greater pulling power and runs smoother. Inside engine, carbon deposits will have built up from previous un-boosted running and these deposits get burnt away when you use a booster and that internal cleaning extends the engine life.

3.2 Working principle

We need to feed the engine with three things:

- Air - this is fed in as normal through the existing air filter.
- Hydroxy gas - how to make this has already been explained in considerable detail.
- A mist of very small water droplets, sometimes called "cold water fog".

Also, we need to make two adjustments to the engine:

- The spark timing needs to be retarded by about eleven degrees.
- If there is a "waste" spark, then that needs to be eliminated.

To summarise then, a good deal of work needs to be done to achieve this effect:

- An electrolyser needs to be built although the required gas production rate is not particularly high.
- A generator of cold water fog needs to be made or bought.
- Pipes need to be installed to carry these two items into the engine.
- The engine timing needs to be retarded.
- Any waste spark needs to be suppressed.
- Water tanks are needed for the cold water fog and to keep the electrolyser topped up.
- Ideally, some form of automatic water refill for these water tanks should be provided so that the generator can run for long periods unattended.

A generalised sketch of the overall arrangement looks like this:

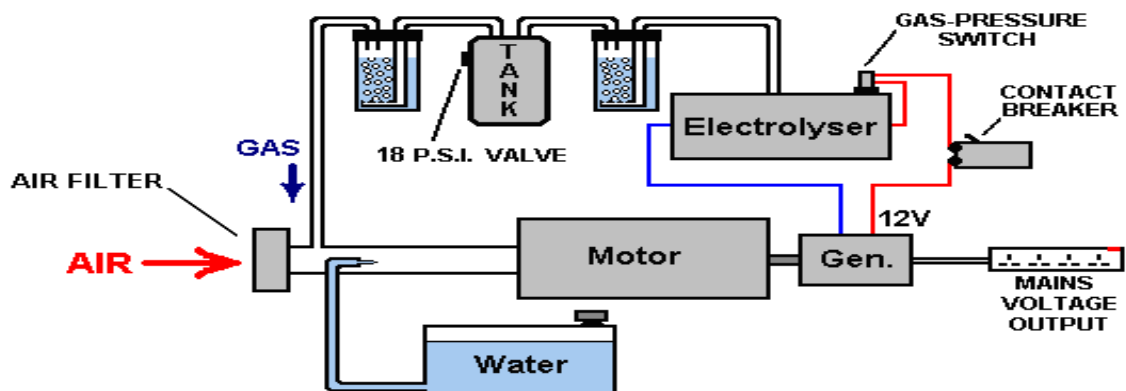
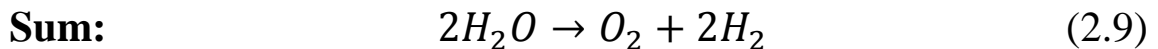
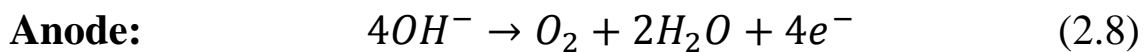
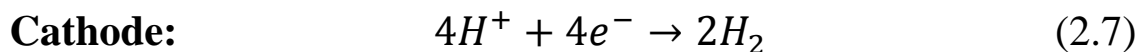
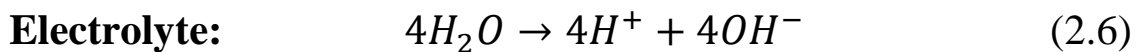


Figure3.1: hydroxy system

Here, they have opted to feed the hydroxy gas into the air system after the air filter (a thing which we normally avoid as it is not helpful for the hydroxy gas production efficiency, but the first step is to reproduce their successful method exactly before seeing if it can be improved further). Also fed into this same area is the cold water fog which is comprised of a very large number of very tiny droplets. The air enters this area as normal, through the existing air filter. This gives us the three necessary components for running the generator engine without using any fossil fuel.

3.3 Alkaline electrolysis

Alkaline electrolyzers use an aqueous KOH solution (caustic) as an electrolyte that usually circulates through the electrolytic cells. Alkaline electrolyzers are suited for stationary applications and are available at operating pressures up to 25 bar. Alkaline electrolysis is a mature technology, with a significant operating record in industrial applications, that allows remote operation. The following reactions take place inside the alkaline electrolysis cell:



3.4 Working principle of the electrolyzer

Two metal plates are placed in water and an electric current is passed between the plates. This causes the water to break down into a mixture of hydrogen gas and oxygen gas (The two components used in the Space Shuttle). The greater the flow of current, the larger the volume of gas which

will be produced. The arrangement is like this:

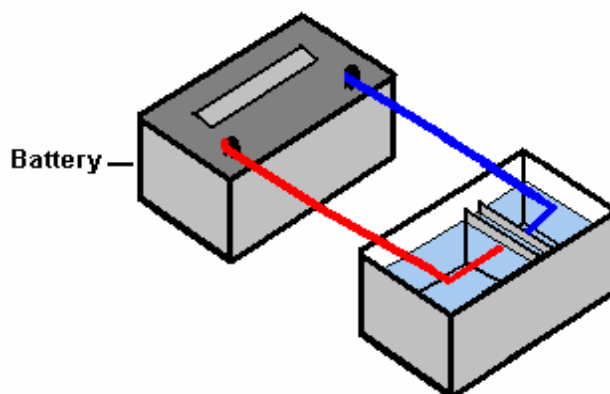


Figure3.2: single cell

This style of electrolysis of water was investigated by the very talented and meticulous experimenter Michael Faraday. He tells us that the amount of hydroxy gas produced is proportional to the current flowing through the water, so to increase the rate of gas production, you need to increase the current flow. Also, he found that the optimum voltage between the two "electrode" plates is 1.24 volts.

This sounds a bit technical, but it is a highly useful piece of information. In the arrangement shown above, twelve volts is being connected across two plates in water. Faraday tells us that only 1.24 volts of that twelve volts will go to make hydroxy gas and the remaining 10.76 volts will act as an electric kettle and just heat the water, eventually producing steam. As we want to make hydroxy gas and not steam, this is bad news for us. What it does tell us is that if you choose to do it that way, then only 10% of the power taken by the booster actually makes hydroxy gas and a massive 90% is wasted as heat. One way around the problem is to use two cells like this:

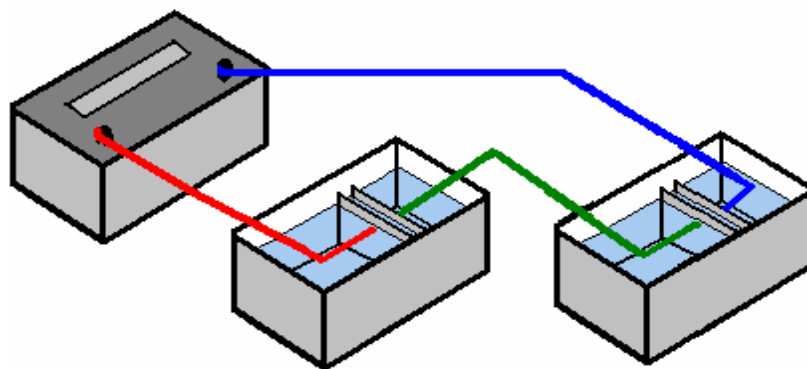


Figure3.3: pair of cell in series

This arrangement uses our 1.24 volts twice while the twelve volts stays unchanged and so the electrical efficiency goes up to 20% and the heat loss drops to 80%. That is quite an improvement but even more important is the fact that twice as much hydroxy gas is now produced, so we have doubled the electrical efficiency and doubled the gas output, giving a result which is four times better than before.

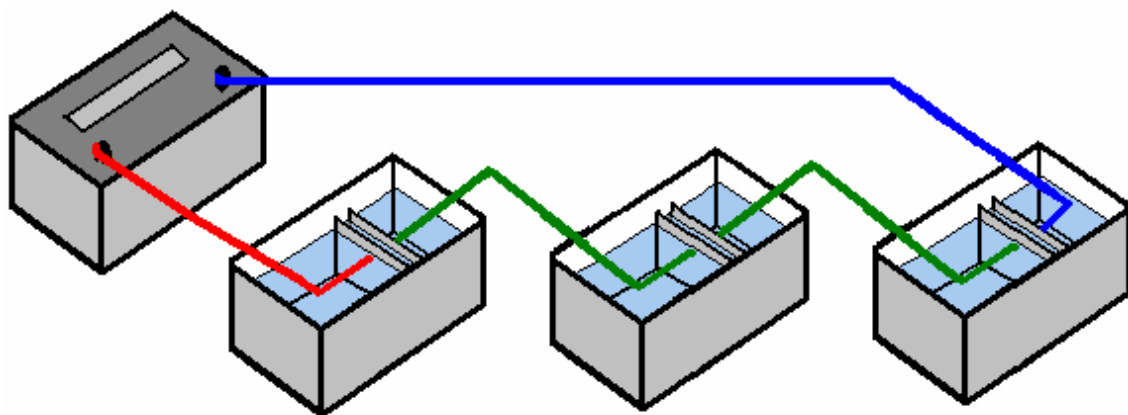


Figure3.4: three cell in series

This time we are using three of our 1.24 volt sections and this gives us an electrical efficiency of 30% and three times the amount of gas, making the system nine times more effective.

This is definitely going in the right direction, so how far can we take it

when using a twelve volt battery? When we use the construction materials which years of testing has shown to be particularly effective, there is a small voltage drop across the metal plates, which means that the very best voltage for each cell is about 2 volts and so with a twelve volt battery, six cells is about the best combination, and that gives us an electrical efficiency of 62% and six times as much gas, which is 37 times better than using a single cell, and the wasted electrical power drops down from 90% to 38%, which is about as good as we can get.

Of course, it would not be practical to have six boxes each as large as a car battery as we would never manage to fit them into most vehicles. Perhaps we could just put all the plates inside a single box. Unfortunately, if we do that, a good deal of the electric current would flow around the plates and not make much gas at all. A top view of this arrangement is shown here:

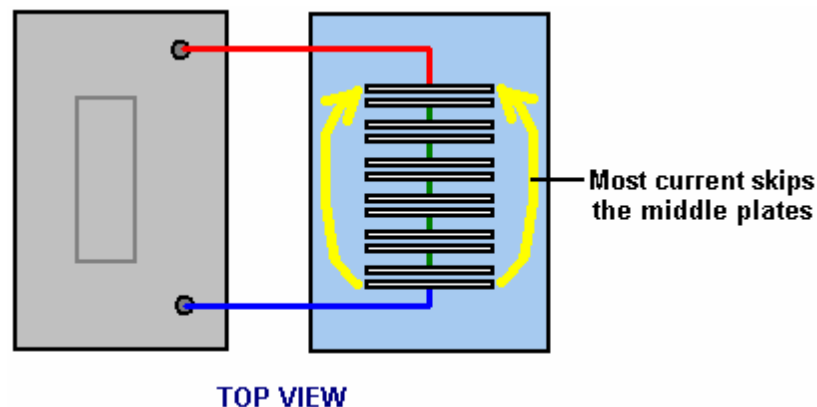


Figure3.5: current flow in the cell

This gives us back our high efficiency by blocking the current flow past the plates and forcing the current to flow through the plates, producing gas between every pair of plates.

We have been discussing the methods of increasing the gas production and reducing the wasted energy, but please don't assume that the objective is to

make large volumes of hydroxy gas. It has been found that with many vehicle engines, very good performance gains can be had with a hydroxy gas production rate of less than 1 litre per minute ("lpm"). Flow rates of as little as 0.5 to 0.7 lpm are frequently very effective. Remember, the hydroxyl gas from a booster is being used as an igniter for the regular fuel used by the engine and not as an additional fuel.

The big advantage of an efficient booster design is that you can produce the wanted volume of gas using a much lower current, and so, a lesser extra load on the engine. Admittedly, there is not much additional engine load needed by a booster, but we should reduce the extra amount by intelligent design.

3.5 The electrolyte

It's a mix of water and an additive to allow more current to flow through the liquid. Most of the substances which people think of to use to make an electrolyte are most unsuitable, producing dangerous gasses, damaging the surfaces of the plates and giving uneven electrolysis and currents which are difficult to control.

There are two very suitable substances for this: sodium hydroxide, also called "lye" or "caustic soda". The chemical formula for it is NaOH. One other substance which is even better is potassium hydroxide or "caustic potash" (chemical formula KOH) which can be got from when mixing the electrolyte, never use warm water. The water should be cool because the chemical reaction between the water and the hydroxide generates a good deal of heat. If possible, place the mixing container in a larger container filled with cold water, as that will help to keep the temperature down, and if your mixture should "boil over" it will contain the spillage. Both NaOH and

KOH are very caustic materials and they need to be handled with considerable care. When using sodium hydroxide, the optimum concentration is 20% by weight. As 1 cc of water weighs one gram, one litre of water weighs one kilogram. But, if 20% (200 grams) of this kilogram is to be made up of sodium hydroxide, then the remaining water can only weigh 800 grams and so will be only 800 cc in volume. So, to make up a 20% "by weight" mix of sodium hydroxide and distilled water, the 200 grams of sodium hydroxide are added to just 800 cc of cool distilled water and the volume of electrolyte produced will be about 800 cc.

When potassium hydroxide is being used, the optimum concentration is 28% by weight and so, 280 grams of potassium hydroxide are added to just 720 cc of cold distilled water. Both of these electrolytes have a freezing point well below that of water and this can be a very useful feature for people who live in places which have very cold winters.

3.6 The concentration of the electrolyte

Is very important factor. Generally speaking, the more concentrated the electrolyte, the greater the current and the larger the volume of hydroxy gas produced. However, there are three major factors to consider:

The first one is: In a good electrolyser design like those shown above, the design itself is about as good as a DC booster can get, but understanding each of these areas of power loss is important for the best possible performance. We were taught in school that metals conduct electricity, but what was probably not mentioned was the fact that some metals such as stainless steel are quite poor conductors of electricity and that is why electrical cables are made with copper wires and not steel wires. This is how the current flow occurs with our electrolyser plates:

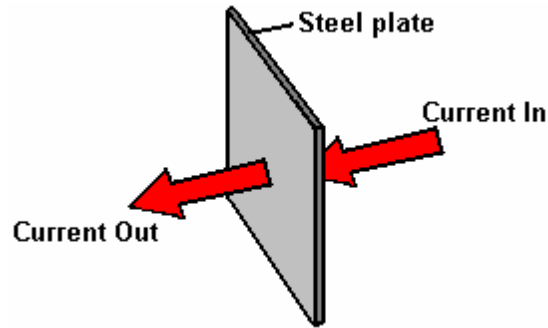


Figure 3.6: current flow in the plate

The fact that we have folds and bends in our plates has no significant effect on the current flow. Resistance to current flow through the metal electrode plates is something which can't be overcome easily and economically, 10 – 11 and so has to be accepted as an overhead. Generally speaking, the heating from this source is low and not a matter of major concern, but we provide a large amount of plate area to reduce this component of power loss as much as is practical.

The second one is : Resistance to flow between the electrode and the electrolyte is an entirely different matter, and major improvements can be made in this area. After extensive testing, Bob Boyce discovered that a very considerable improvement can be made if a catalytic layer is developed on the active plate surface.

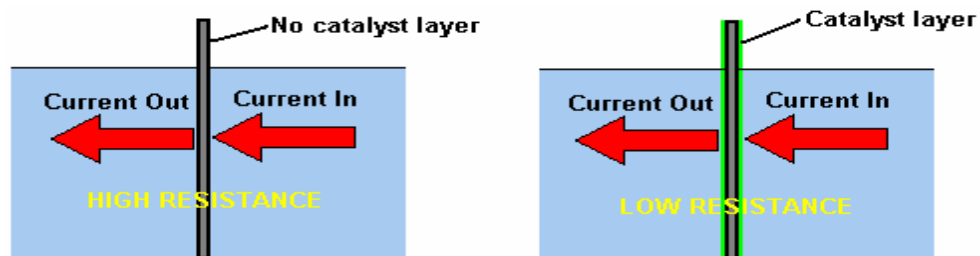


Figure 3.7: effect of catalyst layer

The third one is: Resistance to flow through the electrolyte itself can be minimized by using the best catalyst at its optimum concentration.

CHAPTER FOUR

UNIT DESIGN AND ANALYSIS OPERATION OF HYDROGEN SYSTEM

4.1 Design of the station

Each liter of water produces about 1,750 liters of hydroxy gas, so you can estimate the length of time the booster can operate on one liter of water. The booster is producing 0.6 liter of gas per minute. Then, it will produce 1,750 litres in $1,750 / 0.6$ minutes and that is 2,916.667 minutes or 48 hours 36 minutes, We need three liter per minute to operate 5KW .

4.2 Dimensions of the plates

The plates are held in position by two plastic bolts which run through the original mounting holes in the plates. The arrangement is to have a small 1.6 mm gap between each of plates. These gaps are produced by putting plastic washers on the plastic bolts between each plates. The most important spacing here is the 1.6 mm gap between the plates as this spacing has been found to be very effective in the electrolysis process. Another very practical point is that the stainless steel straps running from the screw cap to the plate array, need to be insulated so that current does not leak directly between them through the electrolyte. The material of the plates is aluminum ,and the dimensions are 5cm*14cm as shown below:

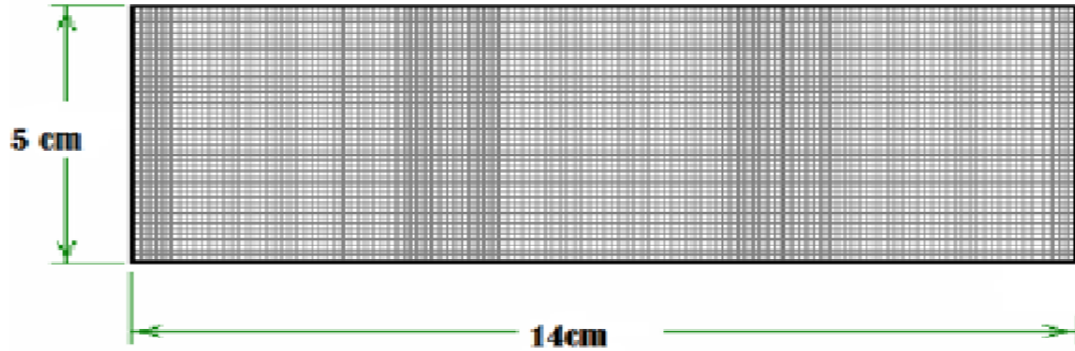


Figure 4.1: the dimension of the plates

4.3 Current calculation

The current is likely to be 4 Amp for each plate then: For 8 plates:

$$8 \times 4 = 32 \text{ Amp} \quad (4.1)$$

4.4 Components of the System

The main components of the system are:

- The electrolyzer Power supply
- The electrolyte
- The electrolyzer
- protection
- Hydrogen use

4.4.1 The electrolyzer power supply

A voltage is applied across the whole set of plates by attaching the leads to the outermost two plates. This voltage should be at least 2.5 volts per cell (according to Michael Faraday), but it should not exceed 2.5 volts per cell. Maintain this voltage across the set of plates for several hours at a time. The current is likely to be 4 amps or more per cell. As this process continues,

the boiling action will loosen particles from the pores and surfaces of the metal.

4.4.2 Adjusting the electrolyte

Fill your booster with distilled water and KOH (potassium hydroxide) only. No tap water, salt water or rainwater No table salt or baking soda These materials will permanently damage the booster. First, fill the booster with distilled water about 2" from the top. Add a teaspoon of KOH to the water about (25% - 30%) and then slide the top into place. Do not tighten it for now, but leave the top loose and resting in place. Connect your 12V power supply to the leads and monitor the current draw of the unit. You want 16 amps flowing when the booster is cold. As the water heats up over time, the current draw will increase by around 4 amps until it reaches about 20 amps, and this is why you are aiming for only 16 amps with a cold system.

If the current is too high, dump out some electrolyte and add just distilled water. If the current is too low, add a pinch or two at a time of your catalyst until the 16 amps is reached. Overfilling your booster will cause some of the electrolyte to be forced up the output tube, so a liquid level tube was added to monitor electrolyte level.

4.4.3 The electrolyzer

The electrical cover plates are clamped together in an array of eight closely-spaced pairs of covers. The plates are held in a vise and the holes drilled out to the larger size needed. The indentations raise the gas output from 1.5 lpm to 1.7 lpm as the both increase the surface area of the cover and provide points from which the gas bubbles can drop off the cover more easily. This type of surface helps the hydroxy bubbles break away from the surface as

soon as they are formed. It also increases the effective surface area of the plate by about 40%. In order to ensure that the stainless steel straps are tightly connected to the electric wiring, the cap bolts are both located on the robust, horizontal surface of the cap, and clamped securely both inside and out. A rubber washer or rubber gasket is used to enhance the seal on the outside of the cap.



Figure 4.2: illustrate the plates



Figure 4.3: illustrate the electrolyzer and the bubbler

4.4.4 Protection

This is the main point we should care about because hydrogen is too risky, the classified to: - Power supply protection

To ensure the safety of the system starting with the cell because the

hydroxyl gas is highly dangerous and its explosive gas so we have to treat it wisely with respect and caution . It's important to make sure that it goes into the engine and nowhere else ,and also important that it gets ignited inside the engine and nowhere else. The source should never be connected directly to electrolyser as there is no protection against a short circuit caused by a loose wire or whatever. There should be a fuse or a circuit-breaker as the first thing connected to the battery. It has to be rated 30 Amp. When using a cell of any design you need to realize that hydroxy gas is highly explosive. A number of common-sense steps need to be taken , Firstly, the cell must not make hydroxy gas when the engine is not running. The best way to arrange this is to switch off the current going to the cell when the engine is not running. It is not sufficient to just have a manually-operated On/Off switch as it is almost certain that switching off will be forgotten one day. Instead, the electrical supply to the cell is routed through the ignition switch of the vehicle. That way, when the engine is turned off and the ignition key removed, it is certain that the cell is turned off as well. So as not to put too much current load on the ignition switch, and to allow for the possibility of the ignition switch being on when the engine is not running, instead of wiring the cell directly to the switch, it is better to wire a standard automotive relay across the oil pressure unit and let the relay carry the cell current. The oil pressure drops when the engine stops running, and so this will also power down the cell. An extra safety feature is to allow for the (very unlikely) possibility of an electrical short-circuit occurring in the cell or its wiring. This is done by putting a fuse or contact-breaker between the battery and the new circuitry as shown in this diagram:

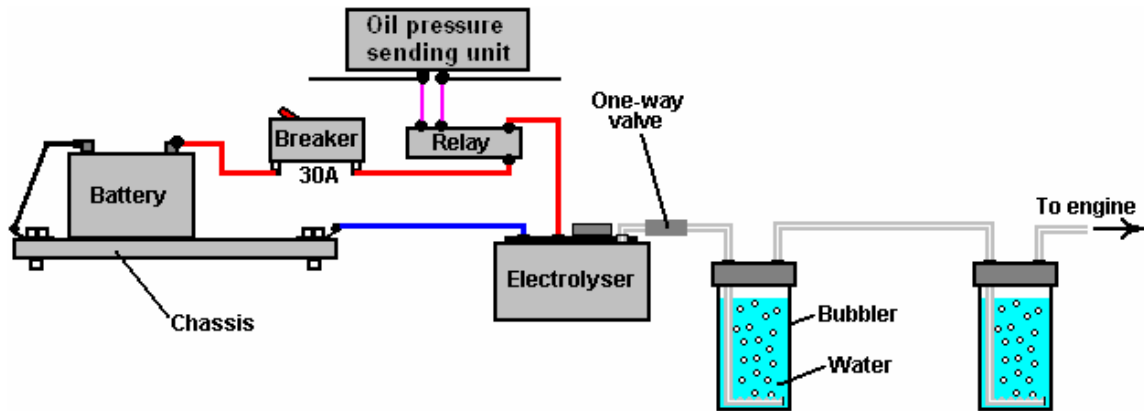


Figure 4.4: the protection scheme

- The Bubbler

A very important safety item for any cell is the “bubbler” which is just a simple container with some water in it. The bubbler has the gas coming in at the bottom and bubbling up through the water. The gas collects above the water surface and is then drawn into the engine through an outlet pipe above the water surface. To prevent water being drawn into the cell when the cell is off for any length of time and the pressure inside it reduces, a one-way valve is placed in the pipe between the booster and the bubbler. If the engine happens to backfire, then the bubbler blocks the flame from passing back through the pipe and igniting the gas being produced in the cell. It also removes any traces of electrolyte fumes from the gas before it is drawn into the engine. In practice, it is a very good idea to have two bubblers, one close to the cell and one close to the engine. The second bubbler makes sure that every last trace of electrolyte fumes are washed out of the hydroxy gas before it enters the engine.



Figure 4.5: illustrate the bubbler

Note: A common mistake is to use a gas pipe which has a small diameter. If you take a length of plastic pipe of a quarter inch diameter (6 mm) and try blowing through it, you will be surprised at how difficult it is to blow through. There is no need to give your cell that problem, so I suggest that you select a gas pipe of half an inch (12 mm) or so. If in doubt as to how suitable a pipe is, then try blowing through a sample length of it. If you can blow through it without the slightest difficulty, then it is good enough for your cell.

The hydroxy gas produced by a DC booster of this type contains about 30% monatomic hydrogen, which means that 30% of the hydrogen is in the form of single atoms of hydrogen and not combined hydrogen pairs of atoms. The monatomic form is about four times more energetic than the combined form and so it takes up a greater volume inside the booster housing. If the booster is left turned off for a long period of time, then these single hydrogen atoms will eventually bump into each other and combine to form

the less energetic diatomic form of the gas. As this takes up less space inside the booster, the pressure inside the booster drops and this has been known to suck water out of the bubbler back into the booster. We don't want this to happen as it dilutes our carefully measured electrolyte concentration and it can make the bubbler ineffective due to lack of water. To deal with this, a one-way valve is put between the cell and the bubbler, positioned so that it does not allow flow back into the cell.

4.6 Results

After operating the electrolyzer at one liter of water, the results are shown below:

Table 4.2: The result table:

Voltage	additions	
12v	-	Small bubbles of hydrogen /poor and slow reaction
24v	-	Small bubbles of hydrogen/speedily reaction
12v	salt	Small bubbles of hydrogen /heating in water
12v	KOH	Increasing in bubbles of hydrogen/Fast reaction /heating in water

Operating at 12v with adding KOH we notice that this is the best status to gain hydrogen.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The calculations that we got from our experiment should be applied on AC synchronous generator, The reasons we could not do that is the cost and hydrogen is critical. This study intends to promote the possibility of using Hydrogen in the Electric Power sector in the Sudan. The motivation for using hydrogen for electricity generation is derived from the fact that the electric power sector is the greatest contributor to green house gas emissions. This problem of emissions must be addressed immediately. Hydrogen serves the purpose as a source of clean energy. The potential for producing hydrogen by making use of renewable energy sources like solar and wind are assessed. There is a huge amount of resource available to produce hydrogen. The resource assessment suggests that the potential available is much more than the energy consumption of the nation. Various means of hydrogen production, handling and delivery to power plants are considered in the study. The suitability of the methods depends upon the production capacity of the hydrogen production plant.

5.2 Recommendations

- Built a unit to distill the water.
- Built a bigger electrolyzer unit (more plates and more tank capacity).
- Built a solar unit to recharge the battery.
- Provide pressure for gas to store more quantities.

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