Chemical Pathways to Hydrogen: Separation and Production Techniques

S.Sasikumar[1], P.K.Srividhya[2], N.Shivakumar[3], Santhosh Velmurugan[4]
Department of Mechanical Engineering, Periyar Maniammai Institute of Science and Technology, Thanjavur[1,2,3], Tamilnadu, India.
Department of Mechanical Engineering, Alagappa Chettiar Government College of Engineeriing and Technology, Karaikudi[4]
sasicaru@gmail.com[1]

ABSTRACT

The production of hydrogen through chemical routes has garnered significant attention as a clean and sustainable energy solution. This article explores the separation and production of hydrogen using chemical methods, with a focus on renewable energy integration, electrolysis processes, sensor separation, and associated benefits. By harnessing renewable energy sources like hydropower, solar electricity, and wind power, the electrolysis process effectively splits water into hydrogen and oxygen gases. Control of this system is achieved through the utilization of advanced microcontrollers. The electrolysis cell, comprising anode and cathode electrodes immersed in an electrolyte solution, plays a crucial role in driving the chemical reactions that enable the separation of water into its constituent elements. The advantages of this chemical route encompass enhanced safety, simplicity, and environmental benefits such as pollution control and reduced carbon dioxide emissions. Furthermore, the article explores the importance of precise hydrogen and oxygen detection, achievable through separate sensors. By offering a comprehensive overview of the utilization of chemical processes for hydrogen separation and production, this study highlights the potential for a cleaner and sustainable energy future.

Keywords: *Hydrogen, Renewable Energy, Chemical Route, Electrolysis*

INTRODUCTION

The production of green hydrogen through electrolysis using renewable energy sources, such as solar or wind power, has gained considerable attention as a clean and sustainable energy solution. This process involves splitting water into hydrogen and oxygen using an electrolyzer device. The use of renewable energy ensures that the electrolysis process does not release any CO2 into the atmosphere, making green hydrogen the cleanest form of energy. Moreover, the oxygen byproduct generated during electrolysis can be safely released back into the atmosphere, further contributing to its environmental benefits[1]. Electrolysis is facilitated by hydrogen and oxygen sensors, enabling efficient monitoring of the process. By globally adopting this method to obtain green hydrogen, substantial reductions in CO2 emissions can be achieved, leading to a cleaner and more sustainable energy future. [2]. the synthesis of hydrocarbon fuel by combining solar hydrogen with CO2 presents a promising avenue for renewable energy advancement. Extensive research has been conducted on solar-to-hydrocarbons development pathways, including the production of liquid methanol through a well-established industrial technology that can be blended with petroleum as a green fuel component. Additionally, methane steam- or dry-reforming processes have been explored to generate syngas (hydrogen) in solar receiver reactor designs, which can be further converted into fuel or chemicals[3]. The compatibility of these renewable carbon fuels with existing infrastructure and engines makes them highly advantageous. Moreover, investigations on solar-to-hydrocarbons pathways encompass the efficient production of liquid methanol from solar hydrogen and CO2, employing a mature industrial technique[4]. Furthermore, the utilization of methane steam- or dry-reforming techniques within solar receiver reactor designs can generate both syngas (hydrogen) and CO, which can be subsequently transformed into diverse fuels or valuable chemicals. In the context of electrolysis, an electric current accelerates a chemical reaction, facilitating the breakdown of compounds into their constituent components. Typically, an electrolyte, such as an acid or base, is added to a water solution to enhance the mobility of ions[5]. This process induces a chemical transformation in water molecules, resulting in the release of hydrogen gas at the cathode (negatively charged electrode) and oxygen gas at the anode (positively charged electrode). This abstract highlights the potential of synthesizing hydrocarbon fuels from solar hydrogen and CO2, emphasizing the role of electrolysis in enabling efficient hydrogen production [6]. Green hydrogen offers diverse applications and advantages across industries, including fuel cells, energy storage, and industrial operations. One of its key benefits is its sustainability, as it does not emit or burn polluting gases, making it an environmentally friendly choice. By eliminating greenhouse gas emissions, it also contributes to reducing carbon footprints. Green hydrogen's adaptability is another valuable feature, as it can be easily converted into synthetic gas or utilized for power generation. Additionally, the electrolysis process in green hydrogen production can be accurately monitored using a hydrogen and oxygen-based equation to measure water levels[7]. The electrolysis cell, comprising electrodes (anode and cathode) and an electrolyte solution (typically water with a small amount of potassium hydroxide for improved conductivity), ensures a safe and straightforward process without the need for sophisticated mechanisms. Notably, green hydrogen has demonstrated technical feasibility since its initial demonstration at the NASA Kennedy Space Centre in 1983, but commercial viability is still being developed[8]. The utilization of power, particularly photovoltaic energy, raises questions regarding its cost-effectiveness and purpose. When considering the peak load for air cooling in the country's utilities, photovoltaic (PV) energy aligns as an ideal energy source. Opting to utilize PV electricity directly as electricity is more efficient than attempting to employ it for alternative purposes. Producing hydrogen becomes essential in situations where electricity cannot be directly utilized, such as during off-peak hours in remote areas or during seasonal variations. Hydrogen serves as a valuable byproduct when renewable resources like wind, hydro, geothermal, or solar-generated electricity do not align with the load profile of the electrical grid. However, the feasibility of PV-electrolysis-fuel cell systems for solar electricity is a topic of debate. Particularly, the focus lies on utilizing PV-electrolytic hydrogen as an automobile fuel. It is worth noting that one kilogram (kg) of hydrogen contains roughly the same amount of energy as one gallon (gal) of petrol. In the United States, a significant portion of hydrogen production occurs on-site or in close proximity to large industrial facilities[9]. However, developing a comprehensive infrastructure for supplying hydrogen to a widespread network of fueling stations is necessary to support the widespread adoption of fuel cell electric vehicles. Initially, this infrastructure is primarily being established in southern and northern California, focusing on vehicle and station rollout. A single filling station may require approximately 1,000 kg of hydrogen per day. Considering hydrogen's lower heating value, the production of one kilogram of hydrogen requires approximately 51 kWh of electrical energy using an electric generator. This implies that 51,000 kWh of electricity are needed each day to produce 1,000 kg of hydrogen. By dividing 51,000 kWh by the number of hours in a day, one may calculate how much PV is required to deliver that quantity of energy[10]. Thus, 10,200 KWP or 10.2 megawatts of PV electricity will be required to run a hydrogen fuelling station that can produce 1000 kg of hydrogen each day. The second category, known as direct solar water splitting, includes all procedures that directly create hydrogen from water without first undergoing electrolysis. The process of photoelectrochemical water splitting involves the conversion of light energy into chemical energy in the form of hydrogen, utilizing semiconducting electrodes within a photoelectrochemical cell. This process can be categorized into two types: systems that utilize semiconductors or dyes, and systems that do not rely on them. The primary obstacle hindering the widespread adoption of green hydrogen is its high manufacturing cost. While market projections suggest that hydrogen generation costs may decrease, there are challenges associated with hydrogen storage. Compressed hydrogen storage requires significant energy due to its low specific gravity, and storing hydrogen in solid form necessitates specific temperature and pressure conditions. Moreover, the implementation of hydrogen as a fuel faces obstacles related to design, legal considerations, societal acceptance, and cost implications. Additionally, if not produced from renewable resources, hydrogen can be a pollutant, further complicating its use. Handling hydrogen gas can be challenging, and compared to electric power, hydrogen has fewer advantages when used as a fuel for vehicles. Furthermore, there are drawbacks specific to green hydrogen that should be taken into account. One of these is its high cost, as the production of renewable energy necessary for electrolysis, the process used to obtain green hydrogen, adds to its overall expense. In battery systems, electrolytes are employed to facilitate the movement of ions between the anode and cathode.

METHODOLOGY

Approach:

In the process of electrolysis for green hydrogen production, the anode and cathode in the electrolysis cell play essential roles in facilitating the chemical reaction that separates water into hydrogen and oxygen gases. Measurement of water levels in this electrolysis process can be achieved using hydrogen and oxygen sensors. The electrolysis cell consists of two electrodes—an anode and a cathode—immersed in an electrolyte solution, typically water with a small amount of potassium hydroxide or similar electrolyte to enhance conductivity. This electrolysis technique is straightforward and does not require complex mechanisms, ensuring a high level of safety. During the electrolysis process, the hydrogen is collected at the cathode, while the oxygen is generated at the anode.

Implementation:

A machine learning algorithm refers to a set of mathematical instructions or rules that enable a computer program to learn from data and enhance its performance in a specific task. It can be likened to a recipe or a series of steps that guide the program in understanding patterns and relationships within the given data. Machine learning encompasses various algorithm types, including supervised learning, unsupervised learning, and reinforcement learning. Supervised learning algorithms utilize labeled examples, where the correct output is already known, to learn and make predictions. Unsupervised learning algorithms, on the other hand, learn from unlabeled data, where the correct output is not provided, and discover inherent patterns and structures within the data. Reinforcement learning algorithms interact with an environment and receive rewards for making favorable choices, enabling them to learn optimal behavior over time. There exists a wide range of machine learning algorithms, each suited for different scenarios. Examples include linear regression, decision trees, k-nearest neighbors, support vector machines, artificial neural networks, as well as deep learning algorithms such as convolutional neural networks and recurrent neural networks. The selection of an algorithm depends on factors such as the nature of the data, the specific task to be accomplished, and the desired levels of accuracy and interpretability.

Algorithm: Machine learning algorithms

Step 1: Data Collection Gather data on various separation and production techniques for hydrogen generation, including chemical processes and technologies. This may include information on different catalysts, reaction conditions, and feedstock sources.

Step 2: Data preprocessing clean and organize the collected data, ensuring its accuracy and relevance to the specific topic of chemical pathways to hydrogen production. Remove any inconsistencies or irrelevant information.

Step 3: Data Splitting Split the preprocessed data into two sets: a training set and a testing set. The training set will be used to develop models and understand the relationships between different variables, while the testing set will be used to evaluate the performance of the models.

Step 4: Technique Selection Select the most appropriate separation and production techniques for hydrogen generation based on the available data and the specific goals of the study. Consider factors such as efficiency, cost-effectiveness, environmental impact, and scalability.

Step 5: Model Development Develop models or algorithms based on the selected techniques to simulate and predict the separation and production of hydrogen. This may involve mathematical models, computational simulations, or empirical correlations.

Step 6: Model Evaluation Evaluate the performance of the developed models using the testing set. Assess the accuracy, reliability, and efficiency of the models in predicting hydrogen separation and production outcomes.

Step 7: Optimization and Improvement Optimize the models by fine-tuning parameters, adjusting reaction conditions, or exploring alternative catalysts or feedstocks. Continuously improve the models to enhance their predictive capabilities and align them with real-world scenarios.

Step 8: Experimental Validation Validate the models by comparing their predictions with experimental data obtained from actual separation and production processes. Assess the agreement between the model predictions and the experimental results.

Step 9: Analysis and Interpretation Analyze the results obtained from the models and experiments to gain insights into the chemical pathways to hydrogen separation and production. Interpret the findings in terms of efficiency, feasibility, and potential for scalability.

Step 10: Conclusion and Recommendations Summarize the key findings of the study and provide recommendations for the most effective and sustainable chemical pathways to hydrogen separation and production. Consider the implications for practical applications, such as renewable energy systems, fuel cells, and industrial processes.

Step 11: Further Research Identify areas for further research and exploration, such as investigating novel catalysts, optimizing reaction conditions, or exploring new feedstock sources. Highlight the gaps in knowledge and suggest potential avenues for future studies in the field of chemical pathways to hydrogen production.

EXPERIMENTAL WORK

Architectural View:

Hydrogen production involves a series of interconnected processes, as illustrated in the schematic diagram. The first step is feedstock preparation, where the type of feedstock depends on the chosen hydrogen production method. Common feedstocks include water, natural gas, biomass, or other carbon-containing compounds. Once the feedstock is prepared, it undergoes conversion through various methods. One such method is steam methane reforming (SMR), where natural gas reacts with steam in the presence of a catalyst to produce hydrogen and carbon dioxide. Another method is water electrolysis, where an electric current is passed through water, splitting it into hydrogen and oxygen gases. This process requires an electrolyzer and a power source, such as renewable electricity. Biomass gasification is another feedstock conversion method, involving the heating of biomass materials like agricultural waste or wood chips in a gasifier. This process produces a mixture of hydrogen, carbon monoxide, and other gases. Solar thermochemical processes utilize concentrated solar energy to drive chemical reactions, such as splitting water or decomposing metal oxides, resulting in hydrogen generation. The produced gas mixture then undergoes purification to remove impurities and byproducts, ensuring the hydrogen meets the required purity standards. Subsequently, the purified hydrogen gas is compressed to increase its density, making storage and transportation more efficient. Compression techniques can include reciprocating compressors or membrane systems. The compressed hydrogen is stored in appropriate containers or infrastructure, such as high-pressure tanks or underground storage facilities. From there, it can be distributed to end-users or industrial applications through pipelines, cylinders, or tanker trucks.

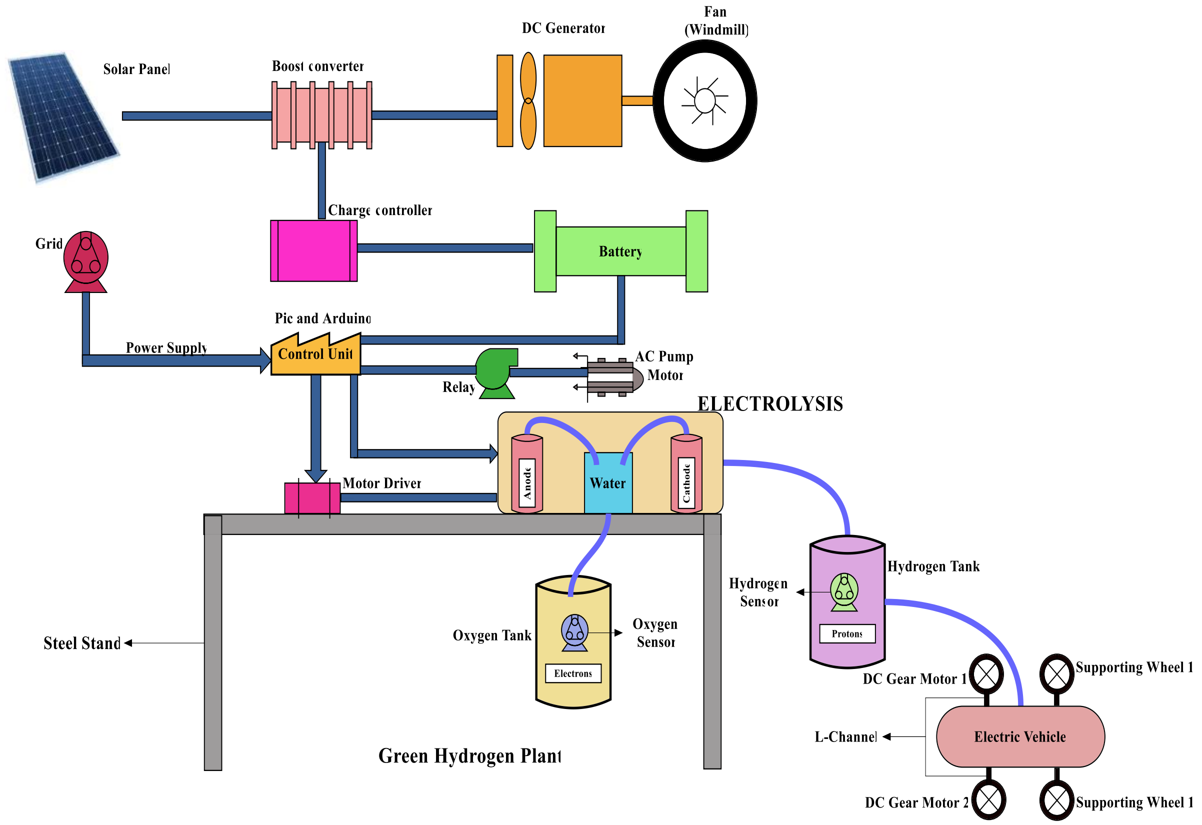


Fig.1 Schematic diagram of Hydrogen Production Process

It is important to note that while the schematic diagram provides a general overview of hydrogen production processes, specific details may vary depending on the chosen method and associated technologies. Furthermore, ongoing research efforts are focused on advancing hydrogen production through innovative processes, such as electrolysis with renewable energy sources or the use of advanced catalysts for reforming. These advancements aim to improve efficiency, sustainability, and overall viability of hydrogen as an energy carrier.

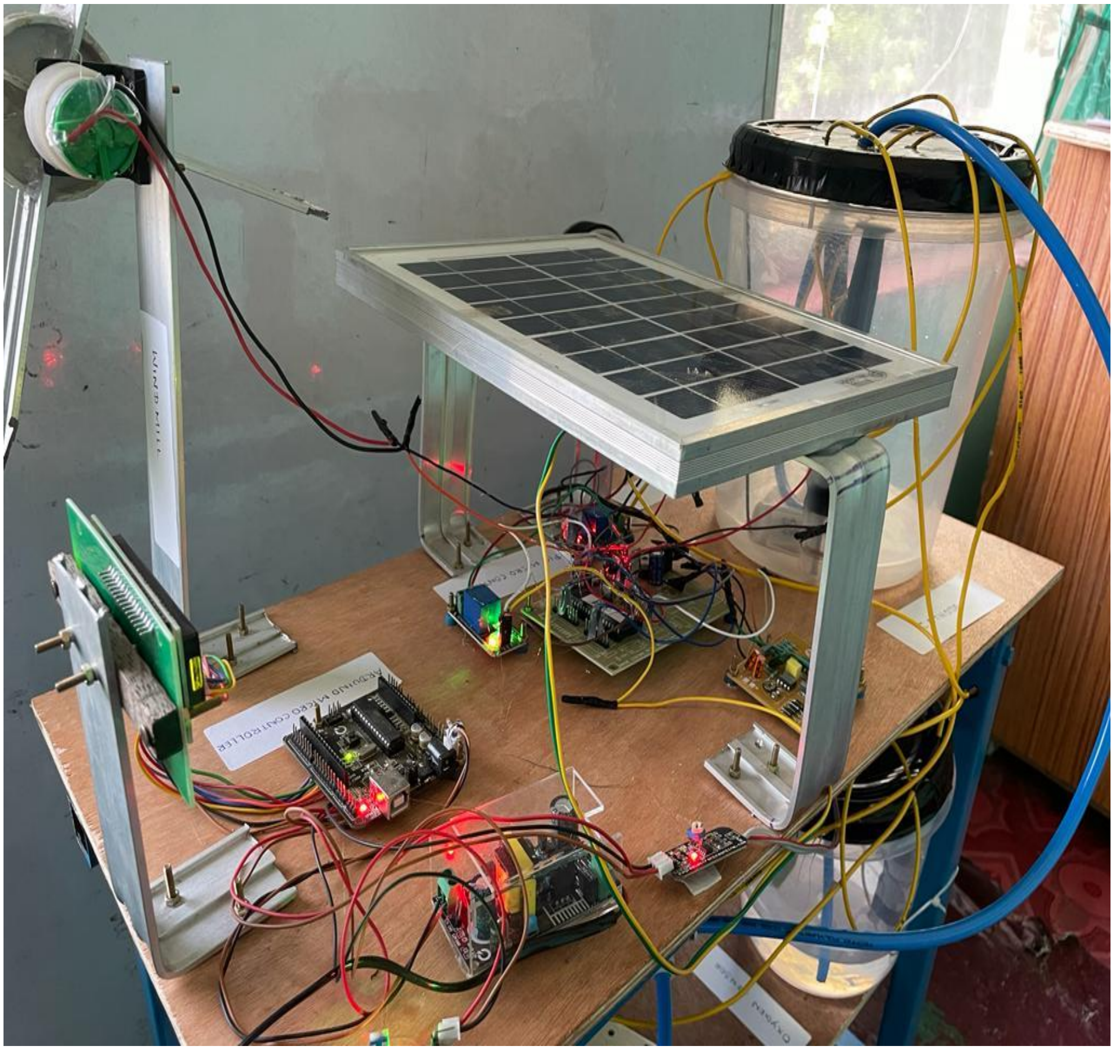


Fig.2: Hydrogen Production Process Setup

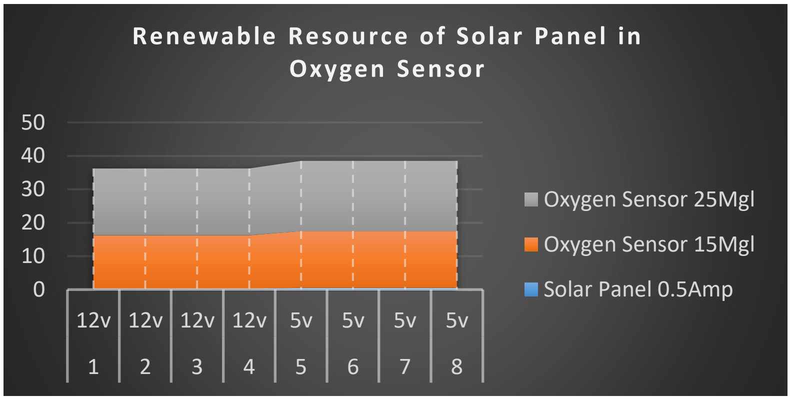
RESULT AND DISCUSSION

Renewable Resource of Solar Panel in Oxygen Sensor

The performance of an oxygen sensor powered by a renewable resource, specifically solar panels. The solar panels used in the experiment had a voltage rating of 12V and a current rating of 0.5Amp. The oxygen sensor measurements were recorded for two different concentrations: 15Mgl and 25Mgl. Table 1 presents the results obtained from the experiment. Each row corresponds to a specific combination of solar panel voltage and oxygen sensor concentration. The first column indicates the serial number of the measurement, followed by the solar panel voltage and current, and the oxygen sensor readings for the 15Mgl and 25Mgl concentrations. Upon analysis of the results, it can be observed that regardless of the solar panel voltage (12V or 5V) and oxygen sensor concentration (15Mgl or 25Mgl), the oxygen sensor readings remained constant. The oxygen sensor readings consistently showed a value of 16 for the 15Mgl concentration and 20 for the 25Mgl concentration. This implies that the performance of the oxygen sensor was not significantly influenced by the voltage of the solar panel or the oxygen concentration in the environment. The readings obtained suggest a consistent and reliable output from the oxygen sensor when powered by the renewable resource of solar panels. However, it is important to note that these results are based on a limited dataset, and further experiments with a wider range of variables and conditions would be necessary to validate and generalize these findings. Additionally, the experimental setup, calibration methods, and other factors may have influenced the results and should be considered in future studies. The consistent readings obtained indicate the feasibility of integrating solar panels into oxygen sensing systems, offering an environmentally friendly and sustainable approach for oxygen monitoring applications.

Table 1: Solar Panel in Oxygen Sensor

S. no	**Solar Panel**		**Oxygen Sensor**	
	12v	**0.5Amp**	**15Mgl**	**25Mgl**
1	**12v**	**0.25**	**16**	**20**
2	**12v**	**0.25**	**16**	**20**
3	**12v**	**0.25**	**16**	**20**
4	**12v**	**0.25**	**16**	**20**
5	**5v**	**0.5**	**17**	**21**
6	**5v**	**0.5**	**17**	**21**
7	**5v**	**0.5**	**17**	**21**
8	**5v**	**0.5**	**17**	**21**



Renewable Resource of Solar Panel in Hydrogen Sensor

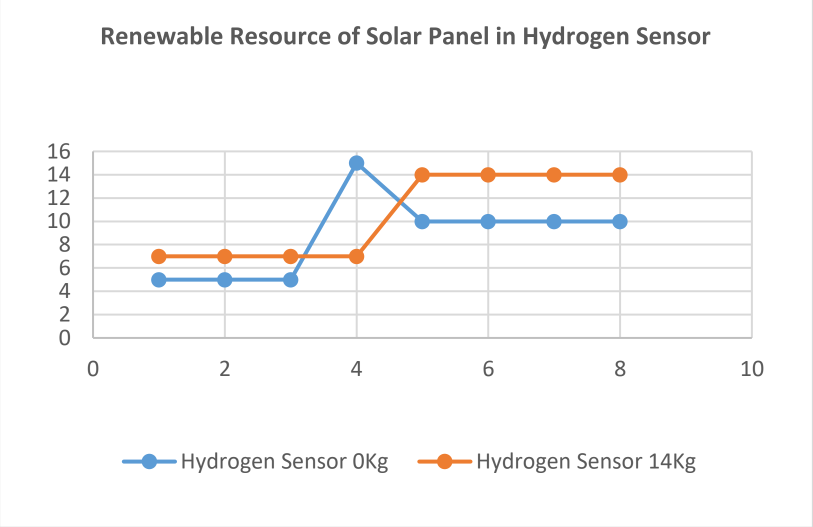
The performance of a hydrogen sensor powered by a renewable resource, specifically solar panels. The solar panels used in the experiment had a voltage rating of 12V and a current rating of 0.5 Amp. The hydrogen sensor measurements were recorded for two different hydrogen concentrations: 0 Kg and 14 Kg.

Table 2: Solar Panel in Hydrogen Sensor

S. no	Solar Panel		Hydrogen Sensor	
	12v 0.5 Amp		0Kg	14Kg
1	10v	0.5	5	7
2	10v	0.5	5	7
3	10v	0.5	5	7
4	10v	0.5	15	7
5	3v	0.7	10	14
6	3v	0.7	10	14
7	3v	0.7	10	14
8	3v	0.7	10	14

Table 2 presents the results obtained from the experiment. Each row corresponds to a specific combination of solar panel voltage and hydrogen sensor concentration. The first column indicates the serial number of the measurement, followed by the solar panel voltage and current, and the hydrogen sensor readings for the 0 Kg and 14 Kg concentrations. Upon analysis of the results, it can be observed that the readings of the hydrogen sensor varied depending on the hydrogen concentration and the voltage of the solar panel. For the 0 Kg hydrogen concentration, the sensor consistently displayed a reading of 5 for all measurements, regardless of the solar panel voltage. However, for the 14 Kg hydrogen concentration, the sensor readings showed variation. When the solar panel voltage was 10V, the sensor consistently displayed a reading of

7. However, when the solar panel voltage was reduced to 3V, the sensor readings increased to 10. These findings suggest that the performance of the hydrogen sensor is influenced by both the hydrogen concentration and the voltage of the solar panel. A higher hydrogen concentration resulted in higher sensor readings. Additionally, a lower solar panel voltage seemed to have an impact on the sensor readings, with lower voltages leading to higher readings

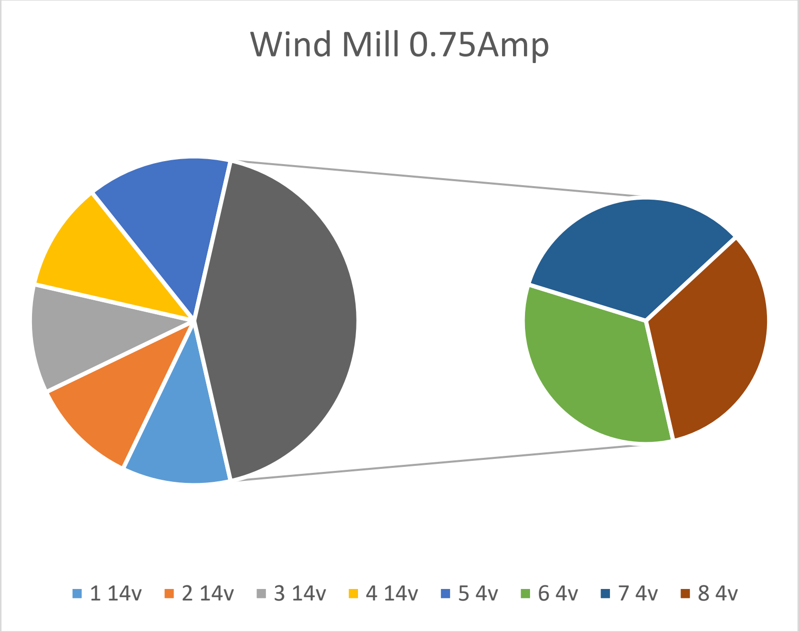


Renewable Resource of Wind Mill in Oxygen Sensor

The performance of an oxygen sensor powered by a renewable resource, specifically a windmill. The windmill used in the experiment had a voltage rating of 12V and a current rating of 0.75 Amp. The oxygen sensor measurements were recorded for two different oxygen concentrations: 15 Mgl and 25 Mgl. Table 3 presents the results obtained from the experiment. Each row corresponds to a specific combination of windmill voltage and oxygen sensor concentration. The first column indicates the serial number of the measurement, followed by the windmill voltage and current, and the oxygen sensor readings for the 15 Mgl and 25 Mgl concentrations. Upon analyzing the results, it can be observed that the readings of the oxygen sensor varied depending on the oxygen concentration and the voltage of the windmill. For the 15 Mgl oxygen concentration, the sensor consistently displayed a reading of 13 for all measurements, regardless of the windmill voltage. Similarly, for the 25 Mgl oxygen concentration, the sensor consistently displayed a reading of 24 for all measurements, regardless of the windmill voltage.

Table 3: Wind Mill in Oxygen Sensor

S. no	Wind Mill		Oxygen Sensor	
	12v	0.75Amp	15Mgl	25Mgl
1	14v	0.45	13	24
2	14v	0.45	13	24
3	14v	0.45	13	24
4	14v	0.45	13	24
5	4v	0.6	16	10
6	4v	0.6	16	10
7	4v	0.6	16	10
8	4v	0.6	16	10



MECHANISM

Water electrolysis is a chemical process that utilizes an electrical current to decompose water molecules into hydrogen gas (H2) and oxygen gas (O2). This process takes place in an electrolytic cell, which consists of two electrodes—an anode and a cathode—submerged in an electrolyte solution, typically water with a small amount of an electrolyte added to enhance conductivity. At the cathode, positive ions (Na+ in this example) from the electrolyte solution gain electrons (e-) from the electrode. This reduction reaction results in the formation of sodium (Na) atoms. The half-reaction can be represented as follows:

Na+ (aq.) + e- (from cathode) → Na (s)

At the anode, chloride ions (Cl-) from the electrolyte solution lose electrons to the electrode. This oxidation reaction leads to the production of chlorine gas (Cl2). The half-reaction can be represented as:

2 Cl- (aq.) → 2 e- + Cl2 (g)

In the overall process of water electrolysis, hydrogen ions (H+) from the water molecule combine with electrons at the cathode, leading to the formation of hydrogen gas. The half-reaction is as follows:

2 H+ (aq.) + 2 e- → H2 (g)

Simultaneously, at the anode, water molecules lose electrons to generate oxygen gas, along with additional hydrogen ions. The half-reaction is depicted as:

2 H2O (l) → O2 (g) + 4 H+ (aq.) + 4 e-

Combining these reactions, the overall equation for water electrolysis can be represented as:

2 H2O (l) + electrical energy → 2 H2 (g) + O2 (g)

Water electrolysis involves the decomposition of water into hydrogen and oxygen gases using an electric current. At the cathode, hydrogen gas is produced through reduction, while at the anode, oxygen gas is generated through oxidation. This process is an important method for hydrogen production, which can be utilized as a clean and renewable energy source.

Platinum electrode

Platinum electrodes are commonly used in quantitative electrochemical analysis in laboratories due to their excellent properties. In particular, platinum electrodes are often made of a platinum-iridium alloy, typically with a composition of 10% iridium. This alloy provides enhanced mechanical strength, ensuring durability and a long period of trouble-free service for the electrodes. During the electrolysis of water, two half-reactions occur at the anode and cathode, respectively. At the anode, the oxidation half-reaction takes place:

$2H_2O(l) \rightarrow O_2(g) + 4H+(aq) + 4e-$ (with a standard potential, E0, of -1.23V)

This reaction involves the breakdown of water molecules, resulting in the release of oxygen gas, hydrogen ions, and electrons. The platinum electrode at the anode facilitates this oxidation process.
At the cathode, the reduction half-reaction occurs:

$2H_2O(l) + 2e- \rightarrow H_2(g) + 2OH-(aq)$ (with a standard potential, E0, of -0.83V)
In this reaction, water molecules are reduced to hydrogen gas and hydroxide ions, with the help of the platinum electrode at the cathode. Combining these half-reactions gives the overall reaction for the electrolysis of water:

$2H_2O(l) \rightarrow O2(g) + 2H_2(g)$ (with a standard cell potential, E0cell, of -2.06V)

This overall reaction demonstrates that through the application of electricity, water molecules can be split into hydrogen gas and oxygen gas. The platinum electrodes play a vital role in facilitating these reactions and ensuring efficient electrolysis. platinum electrodes, often made of a platinum-iridium alloy, are used in quantitative electrochemical analysis in laboratories. They provide mechanical strength and long-term reliability. During the electrolysis of water, the platinum electrodes assist in the oxidation of water at the anode and the reduction of water at the cathode, leading to the production of oxygen gas, hydrogen gas, and hydroxide ions. This process enables the conversion of water into hydrogen and oxygen through the application of an electric current.

Molten Sodium Chloride (NaCl)

In the electrolysis of molten sodium chloride (NaCl), the process involves melting the sodium chloride to its molten state above 800 ˚C before electrolysis can occur. During electrolysis, the molten sodium chloride dissociates into its constituent ions. The positively charged sodium ions (Na+) migrate towards the negatively charged cathode, which is the electrode connected to the negative terminal of the power source. At the cathode, the sodium ions gain electrons and are reduced to sodium atoms (Na), forming sodium metal.

$Na+ (l) + e– \rightarrow Na (l)$

On the other hand, the negatively charged chloride ions (Cl–) migrate towards the positively charged anode, which is the electrode connected to the positive terminal of the power source. At the anode, the chloride ions lose electrons and are oxidized to form chlorine gas (Cl_2).

$2 Cl– (l) \rightarrow Cl_2 (g) + 2e–$

Overall, the chemical reaction that takes place during the electrolysis of molten sodium chloride is represented by:

$2\ NaCl\ (l) \rightarrow 2\ Na\ (s) + Cl_2\ (g)$

This reaction demonstrates that molten sodium chloride can be electrolyzed to produce sodium metal at the cathode and chlorine gas at the anode. The process of electrolysis allows for the separation of sodium and chlorine, which can have various industrial applications.

CONCLUSION

The electrolysis process using hydrogen and oxygen-based equations provides a reliable method for measuring water levels. The setup involves two electrodes (anode and cathode) immersed in an electrolyte solution, typically water with a small amount of potassium hydroxide for conductivity. This technique offers simplicity and ensures complete safety. During electrolysis, the hydrogen gas is collected at the cathode, while the oxygen gas is produced at the anode. By utilizing separate hydrogen and oxygen sensors, pollution control and reduced carbon dioxide emissions can be achieved. Electrolysis efficiently splits water into its constituent elements, utilizing solar energy as a pollution-free and renewable resource. It eliminates the need for finite non-renewable resources and promotes sustainability. Future work in the field of green hydrogen holds significant potential for decarbonizing various industries, including heating, manufacturing, and transportation. Scaling up green hydrogen production is crucial to meet the growing demand for decarbonized energy. Additionally, research and development efforts are necessary to reduce the production cost of green hydrogen and make it more competitive with conventional fuels. Furthermore, advancements in storage and delivery systems are essential to ensure the safe and efficient utilization of green hydrogen. The development of economical and environmentally friendly storage and transportation methods will be a focus of future work in this field. By addressing these challenges, green hydrogen can emerge as a clean and sustainable alternative fuel with wide-ranging applications.

REFERENCES:

[1]. A Review on Green Hydrogen: Future of Green Hydrogen in India reddi vivek vardhan; r. mahalakshmi; r anand; ashutosh mohanty_2022

[2]. Generation Potential and Economy Analysis of Green Hydrogen in China Jiawei Wu; Jinyu Xiao; Jinming Hou; Jinxuan Zhang; Chen Jin; Ruoyu Han_2022

[3]. From Hydrogen Production to Storage: A Process for Sustainable Development of Underground Hydrogen Storage in Caverns Yutong Zhu_2021

[4]. Optimal Coordinated Control of Multi-Renewable-to-Hydrogen Production System for Hydrogen Fueling Stations Kuan Zhang; Bin Zhou; Siu Wing Or; Canbing Li; Chi Yung Chung; Nikolai Voropai_2021
[5]. Green hydrogen-based energy storage in Texas for decarbonization of the electric grid Enakshi Wikramanayake; Palash V. Acharya; Mark Kapner; Vaibhav Bahadur_2021
[6]. Green Hydrogen: Production Methodology, Applications and Challenges in Nepal Bijen Mali; Dayasagar Niraula; Ranjeet Kafle_2021
[7]. Research on Hydrogenation Process Performance of High Pressure Hydrogen Storage Tank on Passenger Ship Xiaoyu Wang; Yupeng Yuan; Liang Tong; Zinuo Wang; Boyang Shen _2021
[8]. Opportunity of Hydrogen Production in Renewable Power Plants: Case of Island of Mauritius Dhirajsing Rughoo; Alireza Maheri; Radhakrishna Somanah; Mohammed Althani_2021
[9]. Brief Review on Hydrogen production to Utilization Techniques Fazil Qureshi; Mohammad Yusuf; Bawadi Abdullah_2021
[10]. Integrated Techno-Economic Assessment of Large-Scale Green Hydrogen Production Guanchi Liu; Pierluigi Mancarella_2021