RJC

RASĀYAN ***J. Chem.***
Vol. 17 | No. 2 |466-471| April - June | 2024
ISSN: 0974-1496 | e-ISSN: 0976-0083 | CODEN: RJCABP
http://www.rasayanjournal.com
http://www.rasayanjournal.co.in

PRODUCTION OF HYDROGEN THROUGH SEAWATER ELECTROLYSIS USING AN EXPERIMENTAL PROTOTYPE

A.J. Yepez-Madrigal, C.A. Sosa-Villalobos✉, and G. Domínguez-Sánchez
Tecnológico Nacional de México/Instituto Tecnológico de Veracruz, Calzada Miguel Ángel de Quevedo 2779, C.P. 91897, Veracruz, México
✉Corresponding Author: cinthya.sv@veracruz.tecnm.mx

ABSTRACT

Hydrogen is a product that has been on the rise over the past decade. Its primary use is as a raw material in industry, but it is also emerging as a provider of electrical power and fuel. A laboratory-scale electrolysis cell was used with seawater employing stainless steel electrodes. Hydrogen production was measured using an electrochemical sensor and an alternating current power source to measure current intensity. A voltage was established in a range of 1,5 to 20 V as the operating condition. The current density (j) behavior in the electrolysis cell increased with increasing applied voltage. Current density ranged from 0,07 A/cm^2 to 3,15 A/cm^2. Hydrogen production efficiency was achieved from 2,5 V onwards, indicating that reaching 1000 ppmH_2 was accomplished in 53 and 34 seconds at voltages of 15 and 20 V, respectively. The results demonstrate direct electrolysis with seawater and its utilization with a renewable energy source.

Keywords: Electrolysis, Hydrogen, Seawater, Current Density, Hydrogen Sensor.

INTRODUCTION

Hydrogen (H_2) is utilized for the production of hydrocarbons, ammonia, fertilizers, and the hydrogenation of heavy hydrocarbons and metals. Additionally, it is employed as fuel in cells to generate heat and electricity.[1] In the year 2022, the average intensity of carbon dioxide (CO_2) emissions derived from hydrogen production was 12 to 13,5 kg per kilogram of H_2. In the same year, the annual demand for H_2 was 95 million tons[2], and it is expected to contribute up to 18% to the energy matrix by the year 2050.[3] Hydrogen is produced from various carbohydrates, such as natural gases, coal, oil, and oil products, which are non-renewable sources and are associated with CO_2 emissions. Nevertheless, it is also possible to obtain it through renewable energy sources or biochemical processes that utilize biomass.[4] Currently, 96% of H_2 is generated from non-renewable sources such as natural gas, petroleum, and steam reforming. Only 4% of H_2 is produced through water electrolysis, a process that utilizes a renewable energy source.[5,6] Electrolysis is an electrochemical process that separates water molecules using electrolytic cells and electrolytes, such as alkaline water electrolyzer (AWE) and potassium hydroxide; proton exchange membrane water electrolyzer (PEMWE) and PFSA membranes; anion exchange membrane water electrolyzer (AEMWE) and DVB polymer support with KOH or $NaHCO_3$; solid oxide electrolysis cell (SOEC) and yttria-stabilized zirconia (YSZ); and proton-conducting ceramic electrolyzer (PCCEL) with (Y,Yb)-Doped-Ba(Ce, Zr)$O_{3-\delta}$.[7] Water from lakes, rivers, and seas is considered a natural electrolyte due to its concentration of dissolved salts, which is why it can be used directly in electrolysis to produce hydrogen.[8,9,10] On the coast of the state of Veracruz, seawater with a salinity of 35 ups has the following composition: chloride (Cl^-) 19,33 g/kg per kilogram of seawater, sodium ion (Na^+) (10,53 g/kg), sodium sulfate ($NaSO4^-$) (1,25 g/kg), magnesium ion (Mg^{2+}) (1,139 g/kg) and sulfate (SO_4^{2-}) (1,06 g/kg). Additionally, it contains the following compounds at 1,0 g/kg of seawater: Br^-, F^-, HCO_3^-, KSO_4^-, K^+, Ca^{2+}, Sr^{2+}, $MgHCO_3^+$, $MgSO_4$, $CaSO_4$, $NaHCO_3$, and H_3BO_3 in lower concentrations.[11,12] Seawater contains sodium chloride, which dissociates into Cl^- ions and Na^+ cations. When a potential difference is applied, positive ions migrate towards the negative pole, and negative ions towards the positive pole. At the anode, for every two Cl^- ions, two electrons are released, forming chlorine gas (Cl_2). At the cathode, the generated electrons decompose water into hydroxide (OH^-) and hydrogen gas.[13] From the experiments conducted with seawater, it is worth mentioning direct electrolysis using copper and graphite electrodes with gradual voltage increases from 1,5 to 24 V, yielding up to 0,77 mL H_2/min.[10] In another study, electrolysis was carried out with seawater using stainless steel

http://doi.org/10.31788/RJC.2024.1728685

electrodes and solar panels as a power source, resulting in hydrogen production of 29,16 mL H_2/min with a power supply of 17,98 V.[13] There have also been reports of the use of stainless steel electrodes for electrolysis with river, lake, and seawater in Turkey. The maximum hydrogen yield was 2,85 mL H_2/min with a photovoltaic panel providing 5,41 kW/m^2/day.[8] In this study, hydrogen production is carried out at a laboratory scale using an electrolysis cell with stainless steel electrodes. This is done to determine operational conditions and efficient hydrogen performance, which will later be integrated into a solar energy system.

EXPERIMENTAL

Material and Methods

The electrolysis cell was constructed using a low-form Griffin beaker made of borosilicate glass from the KIMAX® brand, with a maximum capacity of one liter (Fig.-1). Ethylene-vinyl acetate rubber material was used to hermetically seal the container, with a structure measuring 4,5 cm in height, 10,3 cm in internal diameter, 13,5 cm in external diameter, and immersed 2,8 cm inside the beaker. An acrylic plate measuring eight centimeters in height and 0,2 cm in thickness was attached to the rubber stopper to separate the gases within the chamber.

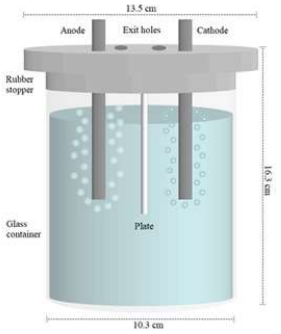

Fig.-1: Experimental Prototype of the Electrolysis Cell

Two cylindrical stainless steel 316 electrodes, each measuring 11 cm in length and 0,6 cm in diameter, were used and incorporated into the rubber structure, providing a contact area with seawater of 13,47 cm^2. To carry out the electrolysis process, a volume of 900 mL of seawater from the coasts of Veracruz, Mexico, was employed. A GW INSTEK model GPS-3303 power supply connected to the electrical grid was used as the power source to control the voltage applied to the cell. The electrodes were connected to the power supply through two electrical conductor cables on the external top part of the cell. The electrolytic system (Fig.-2) consists of a gas sensor connected to a microprocessor that records the data on a computer.

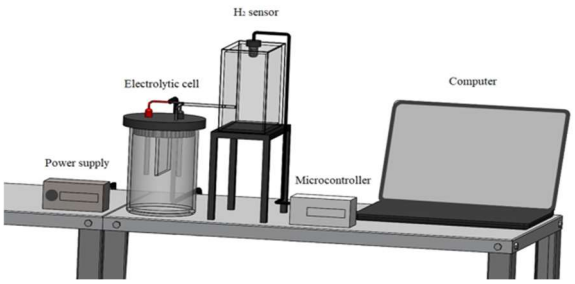

Fig.-1: Employed Electrolysis System

General Procedure

Operating conditions were established by gradually increasing the voltage within a range of 1,5 to 20, and current density and hydrogen yield data were collected.[10]

Detection Method

The current density was determined using the GW INSTEK model GPS-3303 equipment, which was directly connected to the electrodes. This device provided measurements of the current present in the

electrodes during the experimental process. Additionally, the known size of the electrodes was taken into account to calculate the current density. To capture hydrogen, two plastic hoses with a diameter of 0,5 cm were inserted into an acrylic chamber with the following dimensions (14 cm in length, 8 cm in height, and 8 cm in width). This chamber housed a hydrogen gas sensor (ZE03 Electrochemical H_2) from the Winsen brand (Fig.-3).

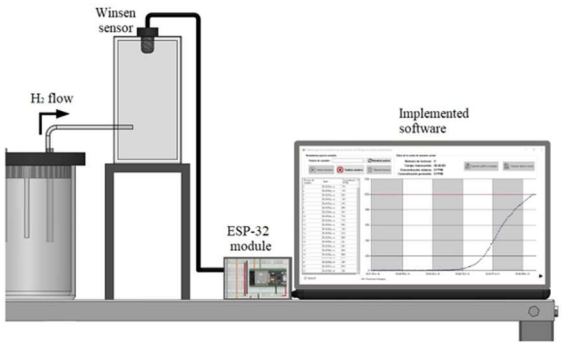

Fig.-2: Hydrogen Capture System

The hydrogen capture system consists of a sensor connected to the PIC16F887 microcontroller integrated into the ESP-32 module. The sensor receives the signal from the module and returns it with measurement data, which the ESP-32 module interprets using software developed with Arduino.

RESULTS AND DISCUSSION

Current Density Behavior

The current density (j) of the cell increased as the voltage was raised (Fig. 4). This is in line with Ohm's law, which states that the current in a circuit is directly proportional to the voltage. The current obtained ranged from 0,07 A/cm² to 3,15 A/cm², within a voltage range of 1,5 V to 20 V. Santos and collaborators determined the current density through electrolysis with 100 ml of water, a stainless-steel cathode (rectangular prism-shaped plates), and a contact surface area of 4,59 cm^2. The results for current density were as follows: 1,7 V = 0,01 A/cm², 1,8 V = 0,02 A/cm², and 1,95 V = 0,05 A/cm².[14] Other researchers used stainless steel electrodes (rectangular prism plates) with a similar contact surface area (4,6 cm²), and the current density at 1,65 V was 0,037 A/cm².[15] These previous studies used contact surfaces smaller than that used in the experimental prototype of this document (13,47 cm²). Lee and colleagues mentioned that the contact surface area is a significant factor, but the application of an electrolyte improves the performance of the electrolysis cell. They implemented an electrolysis cell in the form of a rectangular prism with a contact surface area of 0,5 cm², achieving a current density of 0,025 A/cm² at 1,6 V due to the application of the alkaline electrolyte KOH.[16] On the other hand, they implemented an electrolyzer with an electron exchange membrane in the form of a rectangular prism, and this membrane enhances electron transfer. They used a porous stainless-steel plate as the electrode with dimensions of 2 cm in height, 1 cm in length, and 1 cm in width. The current density obtained was 0,012 A/cm² with 2 V applied.[17]

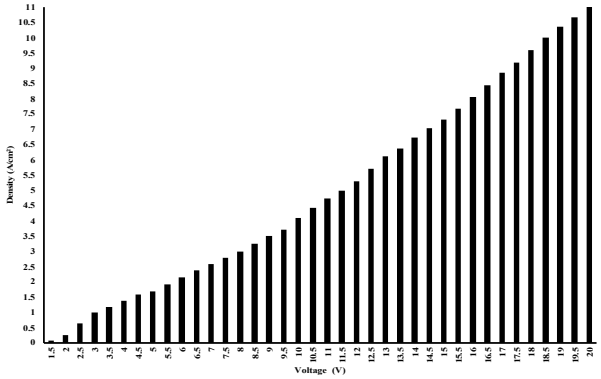

Fig.-4: Current Density (A/cm²) vs. Voltage (V)

According to what was indicated by Lavorante and colleagues, the application of chemical etching treatment with HCl to increase porosity improves current density parameters and reduces resistance by 20% compared to untreated electrodes.[18] In experiments similar to this document, Givirovskiy and colleagues conducted electrolysis with a similar experimental prototype to the one presented in this article (a cylindrical cell). They used stainless steel electrodes with a contact surface area of 13 cm². For the electrolysis, they used distilled water with hydrogen-oxidizing bacteria. They reported current density values of: 2,5 V = 0,005 A/cm², 3 V = 0,0085 A/cm², 3,5 V = 0,0175 A/cm², 4 V = 0,03 A/cm².[19] Furthermore, a cylindrical cell with stainless steel electrodes and a contact surface area of 0,38957 cm² was used, which reduces the cross-sectional area through which the current flows. The current density data obtained were: 1,5 V = 0,07 A/cm², 2 V = 0,13 A/cm², 2,5 V = 0,25 A/cm², 3 V = 0,5 A/cm².[20] The above data are lower than those obtained in the experimental study of this document because the conductivity of seawater is higher than that of tap water and distilled water, resulting in higher current density and faster electrolysis performance.

Hydrogen Yield

In this study, when applying a voltage of 1,1 V, bubbles were observed around the electrode. This indicates that hydrogen production from seawater is possible at voltages below 1,5 V, as the thermodynamic voltage required for electrolysis is 1,23 V.[21] When a voltage of 1,5 V was applied, the yield was 295 ppmH_2 in 1800 seconds, and this value was the average of the experiment conducted in triplicate. To reach a concentration of 1000 ppmH_2, it took 6215 seconds (Table-1). Similarly, a cylindrical cell was used, where they tested with a voltage of 1,5 V and obtained 705 ppmH_2 in 1800 seconds. They used stainless steel electrodes, distilled water, and NaOH-KOH as the electrolyte. However, the H_2 concentration was achieved due to the application of a temperature range of 225-300 ºC, concluding that the increase in current is directly proportional to the applied temperature and voltage.[22]

Table-1: Values of the Estimated Time to Achieve 1000 ppmH_2* in Relation to Voltage

Voltage (V)	Time (s)	Voltage (V)	Time (s)
1.5	6215	11	64
2	1646	11.5	70
2.5	368	12	67
3	273	12.5	62
3.5	253	13	58
4	203	13.5	56
4.5	183	14	64
5	163	14.5	50
5.5	167	15	53
6	144	15.5	46
6.5	123	16	48
7	127	16.5	43
7.5	119	17	38
8	110	17.5	42
8.5	94	18	39
9	91	18.5	40
9.5	79	19	43
10	84	19.5	39
10.5	74	20	34

* Measurement with a hydrogen sensor.

In relation to the experiment in the document, with a voltage of 2 V, it took 1646 seconds to reach 1000 ppmH_2. These results can be compared to those obtained by al-Shara and collaborators, who achieved 2000 ppmH_2 in 1800 seconds by applying high temperatures.[22] When applying a voltage of 3 V, the average concentration of H_2 was 1000 ppmH_2 in 273 seconds. In another study, different voltages were applied, but at 3 V, they obtained 73773 ppmH_2 in 600 seconds. This result was due to the electrolysis being conducted in a cell with 14 electrodes in parallel, deionized water, ZnO as a catalyst, and H_2SO_4 as an electrolyte. The data obtained by Maulana and colleagues show a high yield over a longer period compared to the

experiment in this document, which suggests that the difference in the number of electrodes, the implementation of the catalyst, and the electrolyte played a role in this outcome.[23] The concentration obtained at 12 V was 1000 ppmH_2 in 67 seconds in this experiment. Hydrogen production was rapid compared to lower voltages. Increasing the voltage led to maximum production in less time with the sensor used in this study, as it has a maximum measurement capacity of 1000 ppmH_2. In an electrolytic system implemented by Satrio and colleagues using a cylindrical cell (12 cm in height and five centimeters in diameter) and 600 mL of wastewater from the instant noodle industry, they achieved a yield of 5000 ppmH_2 in 7200 seconds when applying 12 V.[24] When a voltage of 15 V was applied, the sensor detected 1000 ppmH_2 in 53 seconds. This can be contrasted with a water electrolysis experiment that used a real-time TGS 821 sensor connected to a PC via a DAQ. It detected a hydrogen production of 655,76 ppmH_2 with a voltage of 15 V in 660 seconds.[25] Regarding the highest voltage in this document, 1000 ppmH_2 was achieved in 34 seconds with 20 V. It is important to highlight that, unlike the findings of Wardhana and colleagues, who obtained 1226,9 ppmH_2 in 6000 seconds by applying 24 V with distilled water, our study uses seawater. This approach represents a significant contribution as it demonstrates the feasibility of hydrogen production from more abundant resources.[26] The research presented above allows us to observe the similarity in the experimental prototype of this study, with the difference lying in the cell configuration, electrode material, and water used.

CONCLUSION

The development of the seawater electrolysis process at the laboratory level was able to produce hydrogen. By applying higher voltage, the current density increased, demonstrating an increase in hydrogen production. The contact surface area of 13,47 cm^2 of the cell showed a higher current density compared to studies that used smaller contact surfaces. Additionally, the superior conductivity of seawater contributed to efficient hydrogen production. The results defined the feasibility of direct electrolysis using seawater as the electrolyte to be applied in conjunction with a renewable energy source.

ACKNOWLEDGMENTS

The National Council for Humanities, Sciences, and Technologies (CONAHCYT) is appreciated for granting the scholarship (No. 817480) to pursue a master's degree (Master's in Energy Efficiency and Renewable Energies 005845) at the National Technological Institute of Mexico/IT Veracruz. Gratitude is also extended to Swivel Energy, the company that contributed to and supported the project's execution

CONFLICT OF INTERESTS

The authors declare that there is no conflict of interest.

AUTHOR CONTRIBUTIONS

All the authors contributed significantly to this manuscript, participated in reviewing/editing and approved the final draft for publication. The research profile of the authors can be verified from their ORCID ids, given below:

A. J. Yepez-Madrigal https://orcid.org/0000-0003-3717-0022
C. A. Sosa-Villalobos https://orcid.org/0000-0002-2855-9311
G. Domínguez-Sánchez https://orcid.org/0000-0002-9286-1435

REFERENCES

1. The Future of Hydrogen, International Energy Agency, 1-203 (2019), https://www.iea.org/reports/the-future-of-hydrogen
2. https://www.iea.org/energy-system/low-emission-fuels/hydrogen
3. R. Yukesh Kannah, S. Kavitha, Preethi, O. Parthiba Karthikeyan, G. Kumar, N. Vo. Dai-Viet and J. Rajesh Banu, *Bioresource Technology*, **319**, 124175(2021), https://doi.org/10.1016/j.biortech.2020.124175

4. M. Kabeyi and O. Olanrewaju, In Proceedings of the 3rd Indian International Conference on Industrial Engineering and Operations Management, New Delhi, India, pp. 449-468 (2024), https://doi.org/10.46254/IN03.20230165
5. B. Dou, H. Zhang, Y. Song, L. Zhao, B. Jiang, M. He, C. Ruan, H. Chen and Y. Xu, *Sustainable Energy Fuels*, **3(2)**, 314(2019), https://doi.org/10.1039/c8se00535d
6. A. Pareek, R. Dom, J. Gupta, J. Chandran, V. Adepu and P. H. Borse, *Materials Science for Energy Technologies*, **3**, 319(2020), https://doi.org/10.1016/j.mset.2019.12.002
7. M. Chatenet, B. G. Pollet, D. R. Dekel, F. Dionigi, J. Deseure, P. Millet, R. D. Braatz, M. Z. Bazant, M. Eikerling, I. Staffell, P. Balcombe, Y. Shao-Horn and H. Schäfer, *Chemical Society Reviews*, **51(11)**, 4583(2022), https://doi.org/10.1039/D0CS01079K
8. S. Uysal, M. F. Kaya, N. Demir, B. Hüner, R. U. Özcan, Ö. N. Erdem and M. Yılmaz, *International Journal of Hydrogen Energy*, **46(61)**, 31097(2021), https://doi.org/10.1016/j.ijhydene.2021.07.017
9. Y. Kuang, M. J. Kenney, Y. Meng, W.-H. Hung, Y. Liu, J. E. Huang, R. Prasanna, P. Li, Y. Li, L. Wang, M. C. Lin, M. D. McGehee, X. Sun and H. Dai, *Proceedings of the National Academy of Sciences*, **116(14)**, 1(2019), https://doi.org/10.1073/pnas.1900556116
10. C. E. Rustana, Sunaryo, S. J. Muchtar, I. Sugihartono, W. Sasmitaningsihhiadayah, A. D. R. Madjid and F. S. Hananto, *Journal of Physics: Conference Series*, **2019**, 012096(2021), https://doi.org/10.1088/1742-6596/2019/1/012096
11. O. Avendaño-Alvarez, D. Salas-Monreal, M. Marin-Hernandez, D. A. Salas-de-Leon and M. A. Monreal-Gomez, *Regional Studies in Marine Science*, **9**, 145(2017).
12. W. Haynes, Handbook of Chemistry and Fhysics, CRC Press, Boca Raton, p. 14-16 (2016-2017).
13. R. García-Gutiérrez and J. Montes, *ECORFAN Journal-Bolivia*, **8(14)**, 18(2021), https://doi.org/10.35429/EJB.2021.14.8.18.22
14. A. L. Santos, M. J. Cebola, J. Antunes and D. M. F. Santos, *Sustainability*, **15(14)**, 11011(2023), https://doi.org/10.3390/su151411011
15. F. Yu, F. Li and L. Sun, *International Journal of Hydrogen Energy*, **41(10)**, 5230(2016), https://doi.org/10.1016/j.ijhydene.2016.01.108
16. M. Lee, M. S. Jee, S. Y. Lee, M. K. Cho, J.-P. Ahn, H.-S. Oh, W. Kim, Y. J. Hwang and B. K. Min, *ACS Applied Materials & Interfaces*, **10(29)**, 24499(2018), https://doi.org/10.1021/acsami.8b04871
17. S. Stiber, N. Sata, T. Morawietz, S. A. Ansar, T. Jahnke, J. K. Lee, A. Bazylak, A. Fallisch, A. S. Gago and K. A. Friedrich, *Energy Environmental Science*, **15(1)**, 109(2022), https://doi.org/10.1039/d1ee02112e
18. M. J. Lavorante, R. Munaro, J. I. Franco, H. J. Fasoli and A. Sanguinetti, *Avances en Energías Renovables y Medio Ambiente*, **15(9)**, 13(2023).
19. G. Givirovskiy, V. Ruuskanen, L. S. Ojala, M. Lienemann, P. Kokkonen and J. Ahola, *Heliyon*, **5(5)**, e01690 (2019), https://doi.org/10.1016/j.heliyon.2019.e01690
20. I. N. Aquigeh, M. Z. Ayissi and D. Bitond, *S. Hoseinzadeh (Ed.), Journal of Combustion*, **2021**, 1(2021), https://doi.org/10.1155/2021/6673494
21. K. S. Anuratha, M. Rinawati, T.-H. Wu, M.-H. Yeh and J.-Y. Lin, *Nanomaterials*, **12(17)**, 2970(2022), https://doi.org/10.3390/nano12172970
22. N. K. Al-Shara, F. Sher, S. Z. Iqbal, O. Curnick and G. Z. Chen, *Journal of Energy Chemistry*, **52**, 421(2021), https://doi.org/10.1016/j.jechem.2020.04.026
23. F. Maulana, Y. Engge, M. Nurhuda and Istiroyah, *IOP Conference Series: Earth and Environmental Science*, **1097**, 012049(2022), https://doi.org/10.1088/1755-1315/1097/1/012049
24. N. Willy Satrio, Winarto, Sugiono and I. Wardana, *IOP Conference Series: Materials Science and Engineering*, **1034**, 012036(2021), https://doi.org/10.1088/1757-899x/1034/1/012036
25. B. Suryanto, T. I. Nasution, K. Sebayang and S. Khanifah, *IOP Conference Series: Materials Science and Engineering*, **725**, 012055(2020), https://doi.org/10.1088/1757-899x/725/1/012055
26. A. S. Wardhana, U. Yuliatin and A. Yasmin, *Jurnal Polimesin*, **22**, 68(2024)

[RJC- 8685/2023]