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Comprehensive Modeling Study of the Electrical Performance of a Sono-Electrolyzer under a Voltage and Current Sources Supply: From Grey to Green Hydrogen

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Abstract: Hydrogen production from water electrolysis is seen as a promising technology to produce hydrogen with high purity of 99.99%. However, the increase of the ohmic resistance in the electrolyte remains a challenge for the electrolytic technique. In the present work, we study the transition from grey hydrogen to green hydrogen using alkaline electrolysis (25% w/w KOH solution electrolysis). We compare hydrogen production efficiency using a voltage source simulating the conventional DC generator, and a current source simulating the PV power supply. Water electrolysis was coupled to an indirect ultrasound source in order to investigate its effect on hydrogen production process in both cases of power supply. The question was tackled experimentally using an H-cell electrolyzer and an ultrasonic bath, and numerically using a MatLab code. Energy conversion efficiency and hydrogen production rate were determined both experimentally and through simulation. It was demonstrated that the integration of sonication reduces the ohmic resistance within the electrolyzer and thus decreases the cell voltage for the same current, which enhances the energy efficiency in the case of current source for the same hydrogen production rate. For instance, an enhancement of 1% was recorded in the energy efficiency using a current source of energy, while is equals 2.68% in the case of voltage source. Therefore, the coupled of sono-electrolysis process to solar PV seems to be a promising pathway for an environmentally friendly hydrogen production technique from an energetic perspective.

Keywords: Conventional electricity, Hybrid, Water electrolysis, PV, Matlab modeling, Ultrasounds.

Introduction

Global energy consumption has increased as a result of population growth and rising living standards. Therefore, the production of green energy sources has become more urgent due to global warming and environmental emissions (Gielen et al., 2019). The possibility of using hydrogen as a sustainable fuel is a highly attractive topic in the literature. Although most of the technologies that could make a significant contribution are still at an early stage, the introduction of hydrogen as a clean fuel is a key pillar of the decarbonization strategy for industry and transport (Global Hydrogen Review, 2021). Water electrolysis is a clean and sustainable technology that provides the high-purity hydrogen that fuel cells need in particular, to produce clean and sustainable electricity (Boudries, 2013). However, because it is much more expensive than producing H_2 by steam methane reforming (SMR), only a small percentage of the world's H_2 is produced by water electrolysis (Esposito, 2017). This interesting method of hydrogen production accounts for only 4% of worldwide hydrogen production today, however it is estimated to grow significantly in the coming years, to reach 22% by 2050 (Maggio et al., 2022). Besides, the operating expenditure associated with the electricity used to supply electrolysis reaction is currently the largest single cost of water electrolysis (Esposito, 2017; Shaner et al., 2016). However, the cost of green electricity produced by solar PV and wind continues to fall (Esposito, 2017).

Photovoltaic electrolysis (PV-EL) has a comparatively high level of technical maturity (Nour Hane Merabet, Kaouther Kerboua, 2023). However, the overall efficiency of the PV electrolysis system barely attain 10%, as commercial electrolyzers achieve efficiencies ranging from 60% to 85%, while PV cells reach 18% (Song et al., 2022). Several studies have focused on the optimization of these key parameters, as the system efficiency mainly depends on the efficiency of both the PV generator system and the electrolyzer (Nguyen et al., 2019).

Industrial electrolyzers operate at around 70% efficiency when producing hydrogen However, significant power losses due to the Joule effect and parasitic reactions in the solution are a major problem with these systems (Sellami & Loudiyi, 2017). Research has shown the potential for increasing the efficiency of water electrolysis by applying magnetic fields, light energy fields, ultrasonic fields and pulsed electric fields, while only few studies have been conducted on the application of such fields (Burton et al., 2021). The integration of ultrasounds to electrolysis process has been reported to be efficient by several authors (Merabet & Kerboua, 2022). by improving mass transport and electrode cleaning through a combined effect of micro-jetting and micro-flow, and lowering the overall potential through degasification effects or electrode surface modification (Kerboua & Merabet, 2023).

The aim of the present study is to compare the efficiency of sono-electrolysis hydrogen production using a voltage source as a conventional source of electrical energy, i.e., conventional DC generator, and a current source by consisting of a PV power supply, acting as a green energy source for the production of green hydrogen.

Material and Methods

An H-cell electrolyzer composed of anodic and cathodic chambers was used. The volume of the used electrolyte is 300 mL filled with KOH electrolyte at 25% w/w. The adopted parameters are reported in Table.1.

Table 1. Characteristics of the adopted configurations

Parameters		DC generator supplied sono-electrolysis	Pv supplied sono-electrolysis
Power supply	Voltage	5.95 V	According to solar radiation
Electrolyte	Type	KOH	KOH
	Concentration	25% w/w, 4.46 M	25% w/w, 4.46 M
Sonication	Type	indirect	indirect
	Frequency	40 kHz	40 kHz
	Power	60 W_e	60W_e
	Mode	Continuous	Continuous
Electrode's material	Nickel plates	Nickel plates	Nickel plates

The experiments performed using PV supply have been set in order to lead to a cell potential of 5.95 V, this has been met under 827 W/m^2 with silent conditions, and 938.5 W/m^2 with US conditions.

Numerical Modeling

MatLab Modeling

The matlab programm is based on the combination of the PV model and the electrolyzer model according to the list of equations below. The PV current, submitted to a maximum power point tracking, is deuced from Eq.1, based on Eqs. 2 to 4. The resulting polarization curve, linking to current to the potential of the PV panel allows the determination of the feeding current, corresponding to the maximum deliverable power, provided by the MPPT tracker. I_{pv} is the light-generated current of the PV cell is directly dependent on the solar irradiation G.
The current feeding the electrolysis cell governs the values of the overpotentials created in the cell, i.e., the activation overpotential indicated in Eq.7, the Ohmic overpotential as shown in Eq.8, and the concentration overpotential given in Eq.9 (E_{rev} is the reversible voltage, U_{act} is the activation voltage, U_{ohm} is the ohmic voltage and U_{conc} is the concentration voltage). All these overpotentials, added to the reversible potential, determine the cell potential value, according to Eq.5. We pay a particular attention to the ohmic resistance, including the electrolyte resistance, with both bubble free and bubble components, shown in Eqs. 10 to 12, respectively.

Table 2. Mathematical equations of the numerical model

Equations	Number	Reference
$I = I_{pv} - I_d - I_{sh}$	(1)	(Villalva et al., 2009)
$I_{pv} = \frac{(I_{pv0} + K\Delta T)G}{G_0}$	(2)	(Villalva et al., 2009)
$I_d = I_0\left(e^{\left(\frac{R_s I + V}{V_t . a}\right)} - 1\right)$	(3)	(Rahim et al., 2015; Villalva et al., 2009)
$I_{sh} = \frac{V + R_s I}{R_p}$	(4)	(Rahim et al., 2015; Villalva et al., 2009)
$U_{cell} = E_{rev} + U_{act} + U_{Ohm} + U_{Conc}$	(5)	(Mohamed et al., 2016)
$E_{rev}(T,P) = E_{rev}(T) + \frac{RT}{ZF}\ln\left(\frac{P_v{}^{*}(\mathrm{P} - P_v)^{1.5}}{P_v}\right)$	(6)	(LeRoy et al., 1980)
$U_{act} = \frac{2.3026\,RT}{ZFa_a}\log\left(\frac{I_a}{I_{0a}}\right) + \frac{2.3026\,RT}{ZFa_c}\log\left(\frac{I_c}{I_{0c}}\right)$	(7)	(Allen J. Bard, Larry R. Faulkner, 2022)
$U_{ohm} = I(R_{cell} + R_{electrodes} + R_{electrolyte} + R_{electrical})$	(8)	(Abul Kalam Azad & Khan, n.d.)
$U_{conc} = \frac{RT}{ZF}\left(\ln\left(1 - \left(\frac{I}{I_{\mathrm{lim}}}\right)\right)\right)$	(9)	(Mohamed et al., 2016)
$R_{electrolyte} = R_{bf} + R_b$	(10)	(Gambou et al., 2022)
$R_{bf} = \frac{1}{\sigma_{bf}}\left(\frac{d_a}{S_a} + \frac{d_c}{S_c}\right)$	(11)	(Gambou et al., 2022)
$R_b = R_{bf}\left(\frac{1}{\left(1 - \frac{2}{3}e\right)^{1.5}} - 1\right)$	(12)	(Gambou et al., 2022)

The influence of the ultrasound power was evaluated according to the electrode coverage by bubbles e that influences the ohmic resistance as shown in Eq.8-10 in which R_b Bubble resistance, R_{bf} is the bubble free electrolyte resistance, S_a and S_c are anode and cathode cross sections respectively, d_a and d_c are distances from anode and cathode to membrane, σ_{bf} is the bubble-free electrolyte conductivity and finally, the energy conversion efficiency is assessed experimentally according to the Eq.11

$$E_{H_2} = \frac{\dot{m}_{H_2} H_{H_2}}{U_{cell} \times I} \qquad (13)$$

Where $H_{H2} = 142\ MJ/Kg$ and $\dot{m}_{H_2}$ is the flow of produced hydrogen

Results and Discussion

The average values of the mass flow rates of hydrogen produced and energy efficiency, obtained from the respective series of repeated tests (3 trials each), are considered below. In Fig.1, the effects of ultrasound integration on the mass flow rate of H_2 during electrolysis are presented using voltage source (a) and PV solar panel (b). It can be seen that the improvement in the flow rate of hydrogen produced by the integration of continuous ultrasound is higher when a voltage source is used.

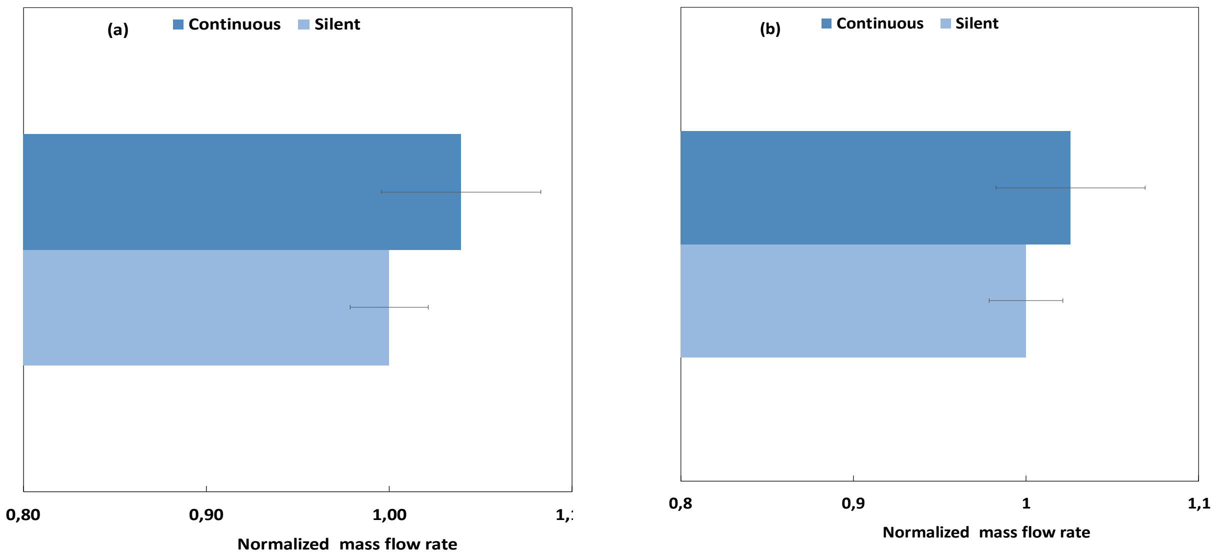

Figure 1. Normalized mass flow rates of hydrogen produced by electrolysis and continuous sono-electrolysis supplied by a voltage source (a) and a PV panel (b)

In Fig.2, the energy efficiency is presented for both power supply (a) voltage source and (b) for PV sources under silent and continuous ultrasound conditions. It can be seen as well that the improvement in the energy efficiency of the process due to the integration of continuous ultrasound is higher when a voltage source is used. For example, a 0.98% improvement in energy efficiency was recorded using a current source, while it equals 2.68% in the case of a voltage source.

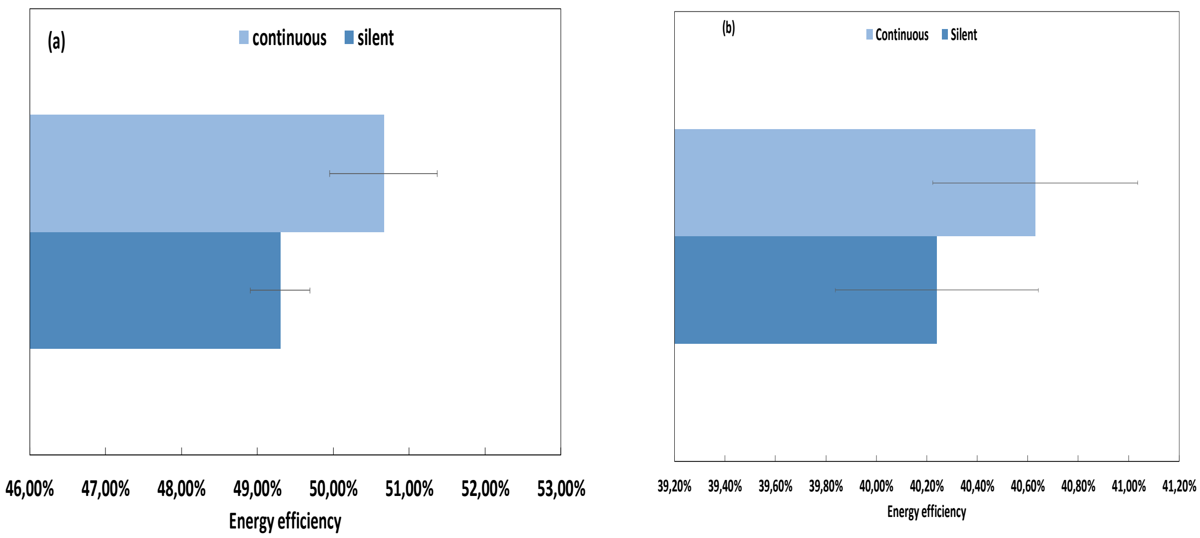

Figure 2. Energy efficiency of hydrogen produced by electrolysis and continuous sono-electrolysis supplied by a voltage source (a) and a PV panel (b).

The improvement obtained with the use of a voltage source is explained by the increase in the current at constant potential due to the drop in the ohmic resistance, which accelerates the kinetics, together with an improved recovery of the gas due to a greater and faster desorption. Hence, in the case of a voltage source, the improvement in H_2 flow rate is due to both effects (increase in current and improved desorption). Whereas in the case of a current source such as the PV supply, for a given delivered current under a given value of global incident solar radiation, the observed improvement in H_2 flow rate can only be explained by the improvement in desorption.

Fig.3 shows the polarization curves under silent and sonicated conditions in continuous mode in order to study the effect of ultrasonic irradiation on the evolution of the current as a function of the electrolysis voltage.

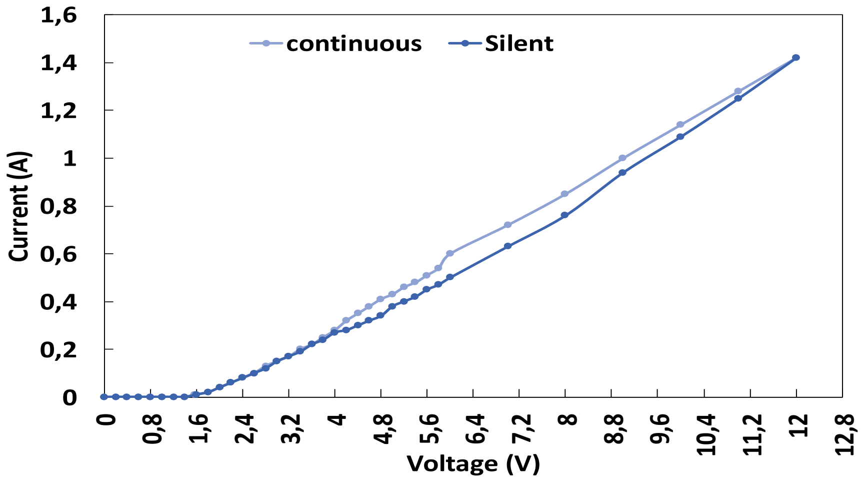

Figure 3. Comparison of I-V curves during water electrolysis and water sono-electrolysis for hydrogen production

Comparing the two curves obtained under silent and ultrasonic conditions shows that sonication increases the value of the current flowing through the electrolysers for a given voltage. The improvement rate in this case is 1.78%, which can be attributed to the efficient enhancement of mass transport due to the propagation of the ultrasound power in the electrolyte solution, which in turn increases electron transport and thus improves the cell current.

Conclusion

A comparative study of the efficiency of grey and green hydrogen production using a voltage source and a solar PV power supply was carried out. It was observed that, the improvement in the flow rate of produced hydrogen due to the integration of continuous ultrasound is higher when a voltage source is used due to the improvement in both current and desorption. In terms of energy efficiency, 1 % improvement has been observed using a current source, compared to 2.68 % using a voltage source. Therefore, a promising avenue for an environmentally friendly hydrogen production technique seems to be the coupling of the sono-electrolysis process with solar PV, particularly from an energetic perspective.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Acknowledgements or Notes

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References

Azad, A.K. & Khan, M. M. K. (2021). *Bioenergy resources and technologies*. Elsiever.

Bard, A. J., Faulkner, L. R., & White, H. S. (2022). *Electrochemical methods: fundamentals and applications.* John Wiley & Sons.

Boudries, R. (2013). Analysis of solar hydrogen production in Algeria: Case of an electrolyzer-concentrating photovoltaic system. *International Journal of Hydrogen Energy*, *38*(26), 11507–11518.

Burton, N. A., Padilla, R. V., Rose, A., & Habibullah, H. (2021). Increasing the efficiency of hydrogen production from solar powered water electrolysis. *Renewable and Sustainable Energy Reviews*, *135*(July 2020), 110255.

Esposito, D. V. (2017). Membraneless electrolyzers for low-cost hydrogen production in a renewable energy Future. *Joule*, *1*(4), 651–658.

Gambou, F., Guilbert, D., Zasadzinski, M., Rafaralahy, H., Gambou, F., Guilbert, D., Zasadzinski, M., Rafaralahy, H., Gambou, F., Guilbert, D., Zasadzinski, M., & Rafaralahy, H. (2022). A comprehensive survey of alkaline electrolyzer modeling : electrical domain and specific electrolyte conductivity To cite this version : HAL Id : hal-03663132 A comprehensive survey of alkaline electrolyzer modeling : electrical domain and specific elect. *Energies*, *15*(9).

Gielen, D., Boshell, F., Saygin, D., Bazilian, M. D., Wagner, N., & Gorini, R. (2019). The role of renewable energy in the global energy transformation. *Energy Strategy Reviews*, *24*(01), 38–50.

Kerboua, K., & Merabet, N. H. (2023). Sono-electrolysis performance based on indirect continuous sonication and membraneless alkaline electrolysis: Experiment, modelling and analysis. *Ultrasonics Sonochemistry*, *96*(February), 106429.

LeRoy, R. L., Bowen, C. T., & LeRoy, D. J. (1980). The thermodynamics of aqueous water electrolysis. *Journal of the Electrochemical Society*, *127*(9), 1954–1962.

Maggio, G., Squadrito, G., & Nicita, A. (2022). Hydrogen and medical oxygen by renewable energy based electrolysis : A green and economically viable route. *Applied Energy*, *306*, 117993.

Merabet, N., & Kerboua, K. (2022). Sonolytic and ultrasound-assisted techniques for hydrogen production : A review based on the role of ultrasound. *International Journal of Hydrogen Energy*, *47*(41), 17879–17893.

Mohamed, B., Ali, B., Ahmed, B., Ahmed, B., Salah, L., & Rachid, D. (2016). Study of hydrogen production by solar energy as tool of storing and utilization renewable energy for the desert areas. *International Journal of Hydrogen Energy*, *41*(45), 20788–20806.

Nguyen, T., Goshome, K., & Endo, N. (2019). Optimization strategy for high efficiency 20 kW- class direct coupled photovoltaic-electrolyzer system based on experiment data. *International Journal of Hydrogen Energy, 44*(09), 26741–26752.

Nour Hane Merabet, Kaouther Kerboua, O. H. (2023). Converting PV solar energy to green hydrogen. In *Reference Module in Earth Systems and Environmental Sciences* (pp. 1–10). Elsiever. https://doi.org/10.1016/B978-0-323-93940-9.00043-8

Rahim, A. H. A., Salami, A., Fadhlullah, M., Hanapi, S., & Sainan, K. I. (2015). Optimization of direct coupling solar PV panel and advanced alkaline electrolyzer system. *Energy Procedia*, *79*, 204–211.

Sellami, M. H., & Loudiyi, K. (2017). Electrolytes behavior during hydrogen production by solar energy. *Renewable and Sustainable Energy Reviews*, *70*(November 2015), 1331–1335.

Shaner, M. R., Atwater, H. A., Lewis, S., & Mcfarland, E. W. (2016). A comparative technoeconomic analysis of energy. *Energy & Environmental Science*, *9*(5), 2354–2371.

Song, H., Luo, S., Huang, H., Deng, B., & Ye, J. (2022). Solar-driven hydrogen production : Recent. *ACS Energy Letters*, *7*, 1043–1065.

Villalva, M. G., Gazoli, J. R., & Filho, E. R. (2009). Comprehensive approach to modeling and simulation of photovoltaic arrays. *IEEE Transactıons On Power Electronıcs*, *24*(5), 1198–1208.

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