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Hydrogen Production by Alkaline Electrolysis: A Study Using the PCC Method

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***Abstract*— An experimental study on the production of green hydrogen through alkaline electrolysis was conducted. The water used is drinking water. Several parameters were investigated, including the type of electrolyte used, the distance between the electrodes, their height, the total supply voltage of the electrolyzer, which indirectly influences the current in the circuit as well as the temperature within the electrolyzer. The results show that increasing the concentration of the electrolyte, regardless of its type, improves the efficiency of the electrolyzer. The same positive effect is observed with an increase in water temperature and electric current. Additionally, the height of the electrodes has a beneficial effect on system performance, as it increases the transfer surface area. Conversely, increasing the distance between the electrodes leads to a decrease in the hydrogen production rate. The efficiency of the electrolysis process also varies depending on the type of electrolyte used: potassium hydroxide proved to be more efficient than the other tested electrolytes. The experimental results are consistent with data reported in the literature. The hydrogen production rate was estimated using a polynomial model. Finally, an optimization of the operating parameters was carried out, aiming to maximize hydrogen production without imposing constraints on the input variables.**

***Keywords*— Green hydrogen; electrolysis; plan of experiments; modelling; optimization**

I. Introduction

Energy production around the world still relies heavily on fossil fuels. This dependence has serious environmental consequences, including air, soil, and water pollution, as well as a significant contribution to greenhouse gas emissions responsible for global warming. In response to this critical situation, an effective and sustainable alternative is the rapid substitution of fossil fuels—high in carbon emissions—with clean, renewable energy sources that do not harm the environment. The acceleration of the energy transition has become a pressing necessity. This transition refers to the gradual shift from a polluting, carbon-based energy system to one powered by renewable, clean, and safe sources such as solar, wind, geothermal, and hydroelectric energy. These renewable sources offer a wide range of benefits: they significantly reduce greenhouse gas emissions, support the decentralization and modernization of energy infrastructure, improve equity in energy access, and help protect public health by reducing exposure to pollutants. Despite these advantages, renewable energies still face certain limitations. Two of the most significant challenges are the high initial investment required for infrastructure—such as solar panels, wind turbines, and hydropower systems—and the issue of intermittency. Renewable energy generation often depends on weather conditions, making its availability inconsistent and sometimes unpredictable. In this context, hydrogen emerges as a promising energy carrier that could complement renewable sources. Hydrogen can serve as a means to store excess renewable electricity and release it when needed. There are various methods of hydrogen production, each with varying degrees of environmental impact, often categorized by colour (such as grey, blue, or green hydrogen). One of the cleanest methods is water electrolysis, which uses an electric current to split water into hydrogen and oxygen—especially if the electricity used comes from renewable sources. A key component in an electrolyzer is the electrolyte, which plays a crucial role in the system's performance. The choice of electrolyte directly affects efficiency by helping to minimize ohmic losses. For industries that rely on hydrogen in their production processes, it is now possible to install on-site electrolysers powered by renewable energy sources like solar or wind, along with a storage unit. This setup allows for the local production of

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green hydrogen, reducing both emissions and the need for transportation. There are several types of electrolysis technologies, each with its own characteristics and energy efficiency. However, the overall efficiency of hydrogen production through electrolysis remains relatively low at present. As such, continued research and development in this field are essential to improve performance, reduce costs, and make this method more competitive with traditional energy sources.

The work is articulated in this context. The studies carried out on alkaline electrolysis are numerous but none of them are planned; each author studies one parameter while keeping the others constant. In this work a planned parametric study using the centered experimental design method is conducted. To predict the response, we have to do a model. To increase the efficiency of hydrogen production by electrolysis, the optimal operating parameters must be identified; therefore, an optimization of these parameters is sought.

II. Methodology and Experimental protocol

The Design of Experiments method involves creating a structured experimental plan that aims to obtain reliable results with a minimum number of tests. Unlike traditional methods, which vary one factor at a time, The Design of Experiments method allows for the simultaneous study of multiple factors, making experimentation more efficient. The main advantages of this approach include a reduction in the number of experiments, the ability to study many factors at once, and the detection of interactions between them. It also enables the development of predictive models with good accuracy and allows for optimization of the process based on these models. Overall, the Design of Experiments method is a powerful tool for improving experimental efficiency and gaining deeper insights into complex systems. The response matrix of the design of experiments is the rate of hydrogen production. The main purpose of the PCC is to mathematically model the studied responses in the form of a 2nd order polynomial equation and to optimize them. This method is also called the Box-Wilson type design which uses the response surface methodology and is used for continuous variables, as is the case with the variation of our variables here. In our study, the answer is the flow of hydrogen produced. The number of factors chosen is five: the concentration of the electrolyte in the electrolyser, the distance between the electrodes, the height of the electrode immersed in the solution, the total supply voltage, the temperature of the solution and the type of electrolytes. The water used is drinking water. The factors and their ranges of variation are listed in TABLE I.

TABLE I
Factor values at different levels

Parameters	Factor level				
	- α	-1	0	+1	+ α
A : Concentration (mol/l)	00.31	01	01.5	02	02.68
B : Distance between electrodes (cm)	03.24	06	08.0	10	12.75
C : Electrode height (cm)	01.62	03	04.0	05	06.37
D : Tension (V)	03.62	05	06.0	07	08.37
E : Température (°C)	39.66	50	57.5	65	75.33

After we fixed the factors and the necessary experimental plan, we carried out the experimental tests to fill the matrices. Fig. 1 gives a schematic representation of the experimental device. The response studied is the rate of hydrogen production. This flow rate is calculated indirectly by calculating the time (t) necessary for the production of a fixed volume of hydrogen for all the tests.

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Fig1. Experimental device

III. RESULTS AND DISCUSSION

All The most important results are the effects and interactions on the response. These effects and interactions are grouped in TABLE II. Given that electrolyte 1 is the sodium hydroxide and electrolyte 2 is the potassium hydroxide.

TABLE II
EFFECTS, INTERACTIONS OF FACTORS AND QUADRATIC EFFECTS

Effects			Interactions			Quadratic effects		
	Electrolyte 1	Electrolyte 2		Electrolyte 1	Electrolyte 2		Electrolyte 1	Electrolyte 2
X0	0.156	0.225	X12	0.002	0.001	X11	0.001	0.006
X1	0.024	0.021	X13	0.002	-0.001	X22	0.004	0.028
X2	-0.016	-0.019	X14	0.005	-0.004	X33	0.001	0.006
X3	0.002	0.015	X15	-0.006	0.007	X44	0.017	0.014
X4	0.076	0.091	X23	-0.005	-0.005	X55	0.0013	0.011
X5	0.028	0.015	X24	-0.005	-0.006			
			X25	-0.004	0.005			
			X34	0.003	-0.008			
			X35	-0.002	0.005			
			X45	0.009	-0.0029			

Concentration has a positive and significant effect regardless of the electrolyte used. This shows that if the concentration of the electrolyte increases the flow rate increases. These results are consistent with those reported in the bibliography. The supply voltage, implicitly the current, has a positive effect and is the most important parameter regardless of the electrolyte used. Fatima Palhares et al found that if the tension increases the production also increases. The distance between the electrodes has a negative and significant effect for both types of electrolytes. That is, if the distance between the electrodes increases then the hydrogen production rate decreases. Indeed, increasing the distance between the electrodes increases the path travelled by the charges, so it limits the production speed. N. Nagai et al have shown that if the space between the electrodes increases then the electrical resistance increases and the efficiency of electrolysis decreases. According to the Stokes-Einstein relation, the diffusion coefficient in the liquid phase is proportional to the temperature. This explains that the operating temperature has a positive and significant effect whatever the electrolyte used. Yang yang Li et al, Boissonneau et al and Damien le Bideau studied the effect of temperature on the efficiency of electrolysis, and they found that if the temperature increases then the production increase. Yang yang Li et al experimentally studied the effect of temperature and pressure under different current densities, they found that if the operating temperature increases the voltage required, for the same amount of hydrogen production, decreases. We can explain this by the fact that increasing the operating temperature increases the activity of the catalyst. The height of the electrodes has a positive and significant Since, if the height increases, the exchange surface increases. The interactions between parameters are generally weak, with the electric current and temperature interaction being the only significant one.

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Similar observations were practically made when distilled water was used in a previous study.

The reduced models found by eliminating insignificant factors are:

- If the electrolyte is sodium hydroxide:

$$D = 0.156 + 0.024A - 0.0162B + 0.076\,D + 0.0279E + 0.019DE + 0.017\,D^2 + 0.011E^2$$

- If the electrolyte is potassium hydroxide:

$$D = 0.223 + 0.021A - 0.019\,B + 0.015\,C + 0.091D + 0.015E + 0.028B^2 + 0.014\,D^2$$

To optimize the hydrogen production process, using this type of electrolyze and if the water used is drinking water, we have set the objective to maximize hydrogen production independently of other parameters. We found the following results:

- Hydrogen flow rate maximize is equal to 0.37 ml/min,
-Concentration is equal to 2 mol/l,
-Distance between electrodes is equal to 6 cm,
-Height is equal to 5 cm,
-Voltage is equal to 7V.

IV. Conclusions and Perspectives

An experimental study on green hydrogen production by alkaline electrolysis was conducted using the Centered Composite Plan method. The parameters studied include concentration, electrode distance, height, voltage, temperature, and electrolyte type. The results show that increasing concentration, electrode height, voltage, and temperature all positively affect hydrogen production, regardless of the electrolyte type. Conversely, increasing the distance between electrodes decreases hydrogen production. The interactions between parameters are generally weak, with the voltage-temperature interaction being the only significant one. The positive effect of temperature on the diffusion coefficient of matter in a medium containing electrolyte is highlighted. Similar observations were practically made when distilled water was used in a previous study. The study also includes optimization of operating parameters for maximum hydrogen production. The results align well with previous studies. In the context of this work, we will adopt the same strategy, but applied to seawater, which is less expensive. However, its high content of chemical components could disrupt the mechanism and damage the electrodes. Future work will focus on exploring suitable materials for electrolyzer electrodes.

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