

Technical Report

## Analyzing the Electrochemical Behaviour of Hydrogen Gas Produced in Single Compartment Electrolyzer

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The relation between power consumption and productivity of the electrochemical reaction was investigated at different environments (Sea water, Sea water mixed with tap water and 0.1N NaCl solution) at ambient and turbulent flow conditions. The results showed an obvious relation between the nature of the environment and the parameters of the voltage balance equation of the electrolyzer. Multiple regression analysis was used to generate a model to show the effect of time and potential on current consumption:

$$\text{Log } I \text{ (measured in } \mu\text{A)} = -0.91185 - 0.00173 t \text{ (min.)} - 0.00496 V \text{ (mV)}$$

This model was selected according to the highest  $R^2$  and  $R^2_{\text{adj}}$  which revealed that the model is significant according to ANOVA statistical analysis based on F and P-tests. On the other hand 3D mapping was generated using MATLAB to show the response of the model.

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**Keywords:** Hydrogen, Seawater, Electrolyzer, Modeling, ANOVA, 3D Mapping

### 1. INTRODUCTION

Hydrogen, which has advantages in highest energy density, environmental friendliness and safety, is considered the energy carrier of the future [1]. Water electrolysis offers significant advantages against other hydrogen producing technologies (hydro, wind, tidal, wave, geothermal, etc.) due to the following[2]: compactness, high current density and small footprint, thus making it easier to collect a large quantity of hydrogen from a small space as the water used after production can be consumed and introduces no additional pollution to the environment.

On the other hand the electrolyzer is considered as a key component in an electrochemical process and special attention must be taken in its design to achieve a high conversion rate of reactant to product as well as a high current efficiency for the desired reaction. Single compartment electrolyzer was utilized in this work to produce Hydrogen gas from sea water, sea water mixed with tap water and 0.1 N NaCl solutions. The important variables in the operation of the electrochemical reactor are concentration of the electrolyte, time of electrochemical reaction, flow rate, temperature and the electrode potential which are considered a key parameter, since reactant conversion, selectivity and current efficiency depend directly on these parameters [3]. If the current through an electrode within the electrolyzer is recorded as a function of electrode potential and the overpotential is very high, an increase in the current is observed due to electrolysis of the supporting electrolyte. Three contributions to the mass transport are normally found due to diffusion, convection, and migration. In many cases forced convection is the predominant factor due to the need to achieve high production rates, especially when treating dilute reactants [4,5 and 6]. The results withdrawn from the applied tests in this work have been represented and correlated in a model based on ANOVA statistical method. The significance of each regressor in this model has been estimated and surface response was drawn using 3D mapping facilities in MATLAB to show the effect of time and potential on current consumption [7].

## 2. EXPERIMENTAL



**Figure 1.** Single compartment electrochemical reactor connected to the flow system used in conducting the experiments .

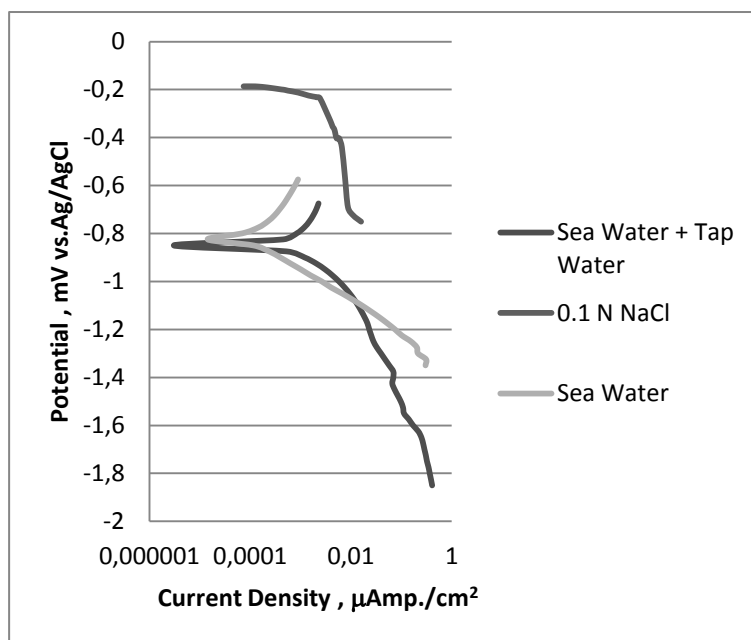
Experiments were conducted using a fabricated single compartment rectangular electrolyzer connected to the flow system shown in fig.(1).The potentiostat (PG STAT30) supplied by Autolab,

Netherlands was used to conduct electrolysis and to build the polarization curves of hydrogen gas production using different electrolytes (Sea water, Sea water mixed with tap water and 0.1N NaCl solution) at constant temperature (ambient) and constant turbulent flow condition.

### 3. RESULTS AND DISCUSSION

#### 3.1 Effect of the environment on the voltage balance equation

The polarization curves given in fig.(2) emphasized on the fact that changing the nature of the environment will have a direct influence on the voltage needed to produce hydrogen at constant temp. (ambient) and constant turbulent flow (i.e.  $\approx 1.1$  V vs. Ag/AgCl when using Sea water,  $\approx 1.6$  V vs. Ag/AgCl when using a mixture of sea water and tap water and  $\approx 0.6$  V vs. Ag/AgCl when using 0.1 NaCl) because currents and potentials, are affected with the fundamental aspects of transport, particularly in turbulent flow conditions which will be reflected directly on the voltage balance equation of the electrolyzer (equ.1) [8, 9, 10, 11]:



**Figure 2.** Represents the potentiodynamic curve of hydrogen evolution at different electrolytes.

$$V_x = V_{\min} + V_{\text{tafel}} + V_{\text{ohm}} + V_{\text{conc}} \quad (1)$$

$V_{\min}$  = the minimum voltage required to achieve electrolysis

$V_{\text{tafel}}$  = the Tafel overpotentials (anodic and cathodic) due to the electrolyzing current

$V_{\text{ohm}}$  = the voltage due to ohmic drop in the solution.

$V_{conc}$  = the voltage due to concentration variation in the solution =  $RT/ZF \ln (1-i_x/i_L)$

The current could be related with the mass transfer coefficient through the following equation:

$$i_x = Z F k (C_b - C_o) \quad , \text{ where } k = \text{mass transfer coefficient (m/s)}$$

When  $i_x = i_L =$  limiting current at  $C_o=0$ , in another word  $i_L = Z F k C_b$

Other power consumption parameters in the voltage balance equation are the ohmic drop which is affected by the height of the electrolyzer (the space between anode and cathode) and the cross-sectional area of the electrolyzer which plays an important role in controlling the pressure drop ( $\Delta P$ ) which will have a direct effect on the production of hydrogen.

### 3.2 Model generation and analysis

Empirical correlation (equ.2) was generated to show the relation between the current as a function of time and potential using sea water in the fabricated electrolyzer. ANOVA test based on F and P-tests with 95% confidence limit was utilized to show the significance of the model as shown in Tables 1,2 & 3:

$$\text{Log } I \text{ (measured in } \mu\text{A)} = - 0.91185 - 0.00173 t \text{ (min.)} - 0.00496 V \text{ (mV)} \quad (2)$$

**Table 1.** Summary of the regression model statistics

Regression Statistics	
Multiple R	0.9867
R Square	0.973578
Adjusted R Square	0.972925
Standard Error	0.075086
Observations	84

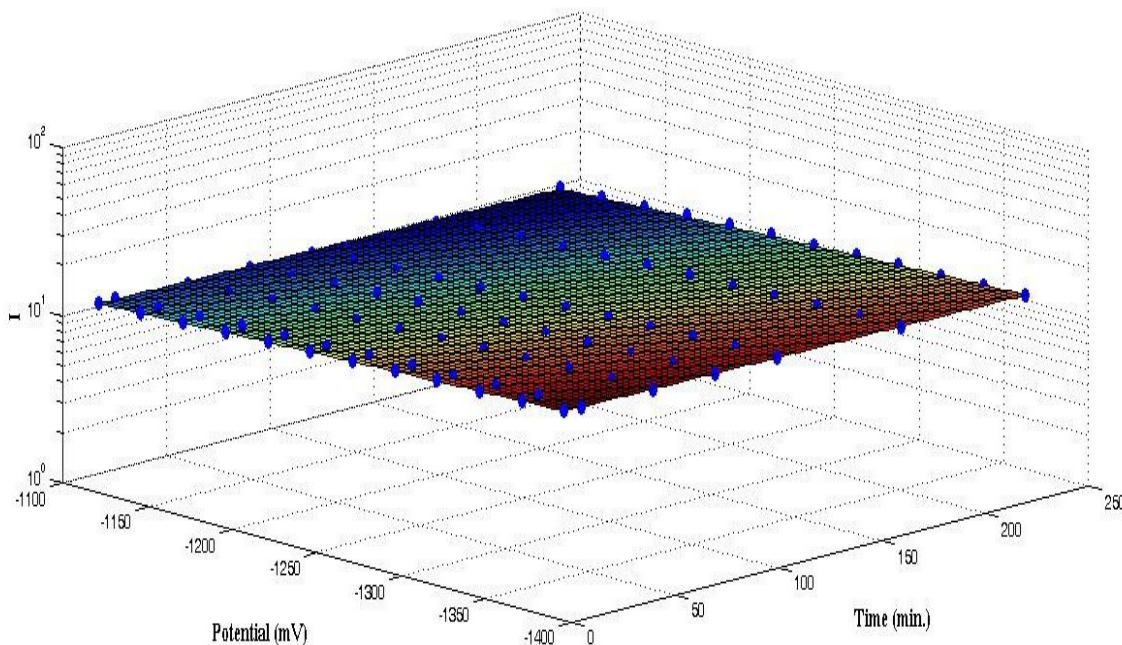
**Table 2.** ANOVA table of the adopted model

	Degree of freedom	Sum Square	Mean Square	F or $f_o$	Significance F or P-value
Regression	2	16.82715	8.413573	1492.305	1.23E-64
Residual	81	0.456676	0.005638		
Total	83	17.28382			

Three dimensional mapping using MATLAB, fig.(3) summarized the effect of both independent variables (time and potential) on current which revealed that the current at which hydrogen gas is evolved is proportional with increasing potential and inversely proportional with increasing time.

**Table 3.** Numerical estimates of the regression model coefficients based on P-value with 95% confidence limit

	Coefficients	Standard Error (Se ( $\beta$ ))	T	P	Lower 95%	Upper 95%
Intercept	-0.91185	0.118299	-7.70801	2.82E-11	-1.14723	-0.67647
Time	-0.00173	0.000108	-16.0343	7.44E-27	-0.00194	-0.00151
log I	-0.00496	9.49E-05	-52.2256	3.83E-64	-0.00515	-0.00477



**Figure 3.** Surface Response for the generated model (equ.1)

#### 4. CONCLUSIONS

A. Optimizing the concentration, time, temp., flow rate, ohmic drop and the pressure drop will have a direct influence on managing the power consumption during the electrolysis process.

B. ANOVA statistical analysis showed that the selected model is significant based on F and P-tests.

C. Three dimensional mapping using MATLAB summarized the effect of both independent variables (time and potential) on current which revealed that the current at which hydrogen gas is evolved is proportional with increasing potential and inversely proportional with increasing time

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