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Stainless Steel Cyclic Voltammograms in Dioscorea Opposita Flour Media

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ABSTRACT

Improving the efficiency of hydrogen gas production in the water electrolysis process draws great attention from many scholars. To improve the efficiency of the process and reduction in the cost, stainless steel has been widely implemented in the industrial water electrolysis process. Electrolyte modification is also one of the methods to improve the water electrolysis process. The study used *Dioscorea opposita* tuber flour as a media addition in an alkaline solution. The efficiency of water electrolysis was evaluated by cyclic voltammetry. The result showed that the activity of the electrode and energy consumption were increased with values of 29 and 23%, respectively, by adding 3 g of the media. However, no media addition showed the lowest energy consumption regarding overpotential value. In general, the *Dioscorea opposita* tuber flour tends to cover the electrode and reduce the activity. Moreover, the utilization of wastewater from *Dioscorea opposita* flour industry is still beneficial to produce hydrogen gas instead of using freshwater.

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1. INTRODUCTION

Stainless steel is a metal alloy that endured corrosion which is suitable as a working electrode in the electrolysis cell. Moreover, stainless steel has been widely implemented on an industrial scale for water electrolysis. It is an alloy of iron that has minimal containing chromium as much as 10.5%. There are many types of stainless steel, for instance of austenitic, ferritic, martensitic, precipitation-hardening, and duplex. Stainless steel is very prospectus as a working electrode on the water electrolysis (Isana *et al*., 2019; Munoz *et al*., 2010), in line with Olivares-Ramirez *et al*., (2007) experiment that is efficiently used as an electrode in the hydrogen evolution reaction (HER) (Sanap *et al*., 2011). The preparation, characterization, and application of electrocatalyst electrode base on stainless steel to produce hydrogen gas had been studied previously.

One of the methods to evaluate electrolysis is using the voltammogram method, linear and cyclic. Voltammogram preserves a curve with the correlation of current and potential which describes good results if it has relatively low overpotential, optimum of adsorption and desorption process, and relatively high cathodic and anodic current peak. This study was implemented cyclic voltammetry to assess the water electrolysis process.

The research regarding the water electrolysis process mostly consists of an electrode, electrocatalyst, and electrolyte. A modification of electrolytes can be conducted by adding some salt or media to improve efficiency. The stainless steel voltammogram pattern on water electrolysis in base solution had been studied (Olivares-Ramirez *et al*., 2007). The addition of media on the water electrolysis had been investigated by many researchers (Colli *et al*., 2019; Sapountzi *et al*., 2017; Tong *et al*., 2020). In General, the efficiency of water remains low because (Schmidt *et al*., 2017).

The addition of media such as fermented flour had been studied by Isana *et al*. (2020). In this study, the addition of Tuber of *Dioscorea spp* was evaluated to improve the efficiency of water electrolysis. As one of the tubers widely planted in Indonesia, *Dioscorea spp* contains high carbohydrates, vitamins, proteins, and minerals. The influence and optimum condition of hydrogen gas production with *Dioscorea spp* tuber flour were evaluated accordingly. The novelty of the study is the addition of *Dioscorea spp* tuber flour as electrolyte media to improve the water electrolysis process. The result of the study could be implemented on the industrial flour wastewater instead of freshwater to produce energy.

2. METHODS

The *Dioscorea opposite* tuber was cleaned and washed from the soil contaminant with also removing the peel. The tuber was sliced and dried by direct sunlight until a constant weight was obtained. The tuber was crushed and sieved accordingly using a 100 mesh sieve.

The water electrolysis was conducted in the base solution (Pletcher, Li, 2011; Sakr *et al*., 2011; Mahrous *et al*., 2011) by adding 5 g $NaHCO_3$ into 1 L of distilled water at room temperature. Stainless steel electrode was used as a working electrode with Ag/AgCl as the electrode reference. The various concentration of *Dioscorea opposite* flour media was added into the system (11 variables). The instrument used in the research were electrolysis tube and eDAQ EChem voltammeter with a 50 mV/s scan rate. The electrode was analyzed by SEM-EDX and gas sorption analysis (GSA) to figure out the composition and quality of the stainless steel.

3. RESULTS

The surface and the composition of stainless steel were identified by SEM-EDX as shown in **Figure 1**. **Figure 1** shows that the

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composition of stainless steel as an electrode consists of Fe and Co. The nickel was not detected during the analysis. The standard stainless steel usually has 16 – 20% Chromium and 8 – 14% Nickel with a balanced amount of iron. The ranging value mainly depends on the stainless steel type. Meanwhile, the GSA gave the surface area, pore volume, and pore radius as much as 6.628 m^2/g, 0.011 cc/g, and 15.318 Å, respectively.

The obtained data from the eDAQ EChem voltammeter was a set of current and potential for every conducted parameter. The data was plotted into a curve, which represents a cyclic voltammogram. The cyclic voltammograms of the stainless steel are shown in **Figure 2**. The bottom peak shows the cathodic current peak, meanwhile, the top peak represents the anodic current peak. The summarized data of cathode current peak and potential is presented in **Table 1**. **Figure 3** shows a relation of tuber *Dioscorea opposite* flour and cathode current peak and potential, which can be used to study the activity of the electrode.

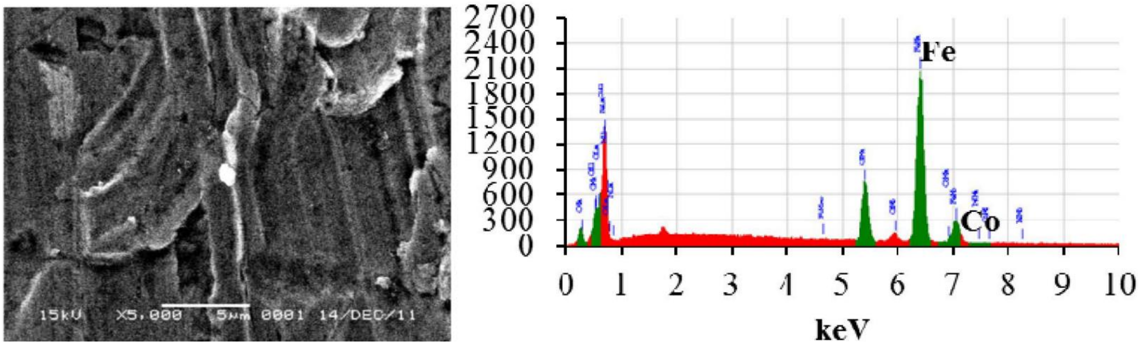

Figure 1. SEM-EDAX analysis of stainless steel electrode.

Table 1. Cathodic current peaks and potential of the systems.

Number of systems	Mass of media (g)	Cathodic peak Current peak (mA)	Cathodic peak Potential (V) versus Ag/AgCl	ΔV (V)
1	0	− 0.2453	− 0.8130	0.015
2	1	− 0.2413	− 0.9980	-0.17
3	2	− 0.2260	− 0.9820	-0.154
4	3	− 0.3155	− 1.0000	-0.172
5	4	− 0.2955	− 1.0000	-0.172
6	5	− 0.2796	− 1.0000	-0.172
7	6	− 0.2792	− 0.9980	-0.17
8	7	− 0.1593	− 1.0000	-0.172
9	8	− 0.2293	− 0.9800	-0.152
10	9	− 0.2145	− 0.9360	-0.108
11	10	− 0.2025	− 0.9350	-0.107

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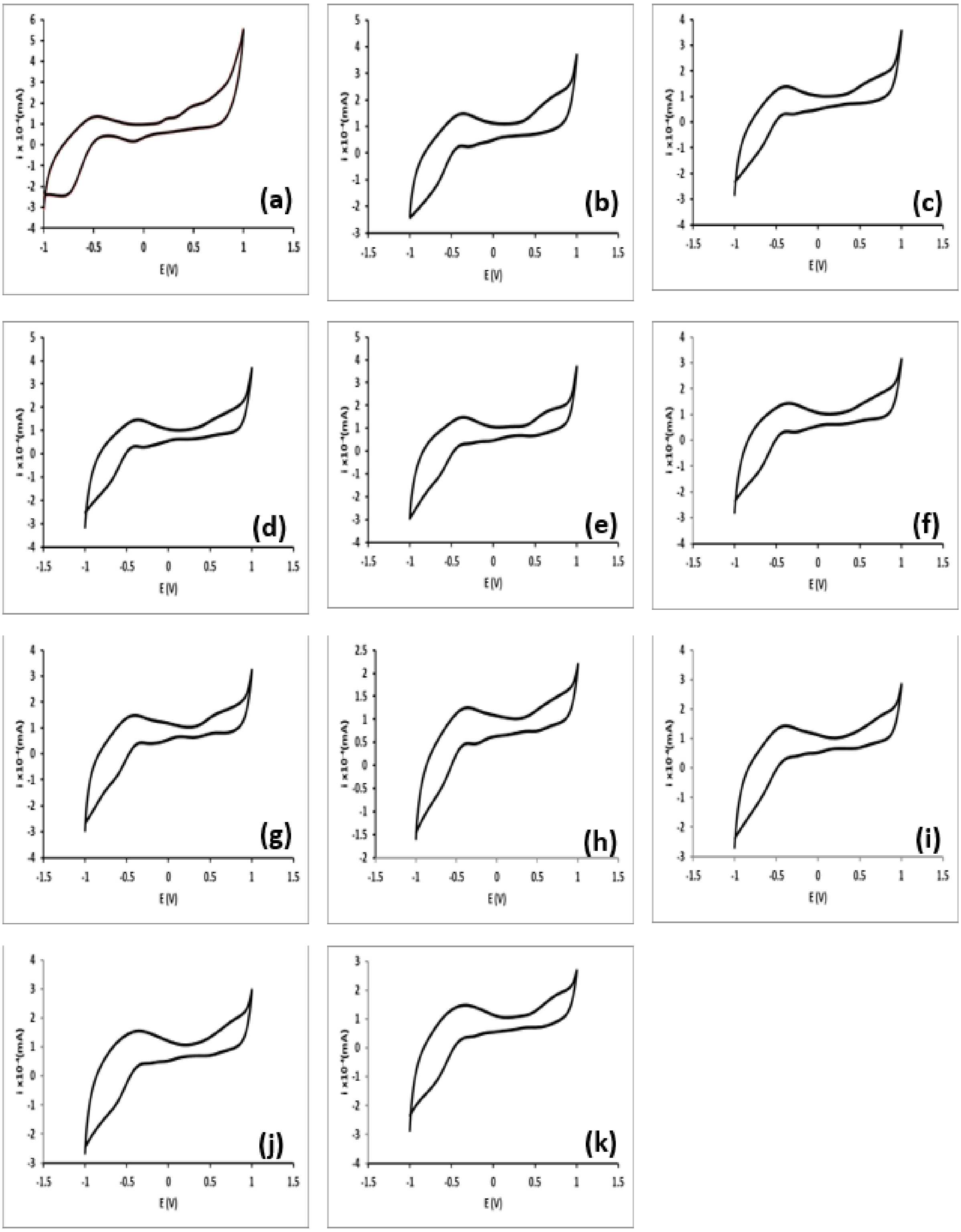

Figure 2. Cyclic voltammogram of stainless steel in tuber *Dioscore opposita* flour media: (a) 0; (b) 1; (c) 2; (d) 3; (e) 4; (f) 5; (g) 6; (h) 7; (i) 8; (j) 9; dan (k) 10 g/L of water.

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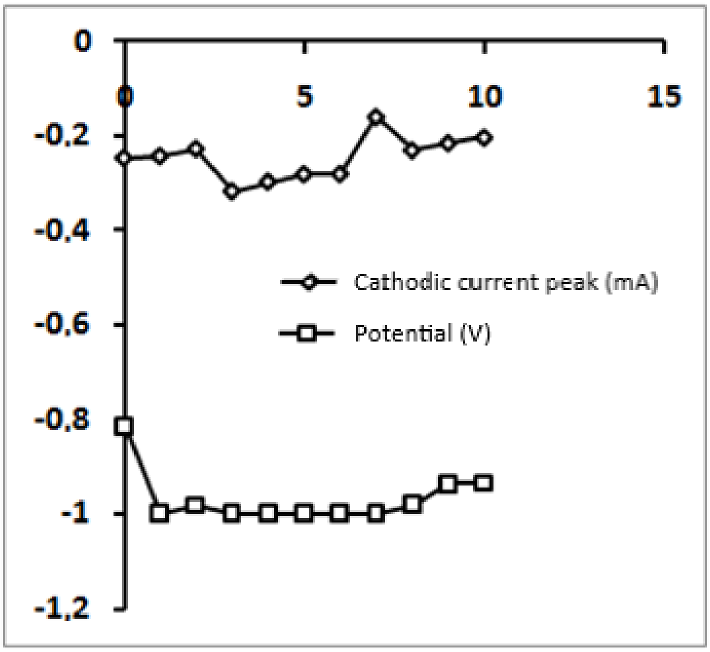

Figure 3. Cathodic current peaks and potential of the stainless steel versus the mass of tuber *Dioscorea opposita* flour.

4. DISCUSSION

The electrolysis reaction, a complex reaction, depends on the electrode potential of the cell component which commonly is over than theoretical potential. The gab of those is called overpotential. Overpotential often occurs on the electrode reaction that involving gas, for example, the overpotential of synthesis of hydrogen gas on Pt surface is lower than 0.5 V (see Equation [1]).

$$\eta = E - E^0 \qquad (1)$$

where η, E, and E^0 respectively are overpotential, potential needed to initiate the electrolysis, and theoretic potential. Overpotential depends on the current flowing through on system (see Equation [2]).

$$\frac{i}{i_0} = \frac{C_O(0,t)e^{-\alpha n/(E-E^0)}}{C_O^{*(1-\alpha)}C_R^{*\alpha}} - \frac{C_R(0,t)e^{(1-\alpha)n/(E-E^0)}}{C_O^{*(1-\alpha)}C_R^{*\alpha}} \qquad (2)$$

where i, C_O, C_R, t, α, n, E-E^0 respectively are current, the concentration of oxidator, concentration of reduction, time (s), a number of electrons, a constant dan overpotential.

The activity of the electrode affects the efficiency of the electrolysis process which is considered from two sides, product, and energy consumption. As the low efficiency becomes the main issue of water electrolysis, the study should overcome in regards to the efficiency upgrading. The higher hydrogen gas produced and the lower energy demand are the primary condition in the investigation. In regards to voltammetry, the higher hydrogen gas produced is in line with the current (i) as described in Equation [2]. Meanwhile, the amount of energy is in accordance with the recorded potential of the electrolysis system which is corresponding to Equation [3] of Gibbs free energy and cell potential.

$$\Delta G = -nFE \qquad (3)$$

The cyclic voltammetry describes the electrode activity on the water-splitting process. In this study, stainless steel voltammetry on the alkaline condition was carried out in the presence of *Dioscorea opposita* flour media. As shown in **Figure 1** (d), the addition of 3 g media showed the best electrode activity. It is shown by 29% of

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the increased activity with 23% energy addition compared to the sample control (blank). In this condition, the adsorption and desorption of hydrogen gas occur optimally.

To justify the optimum condition, product efficiency was calculated based on the cyclic voltammetry results. However, the data showed that the optimum condition occurs at the blank solution without media addition because it requires the lowest energy on the water-splitting process, lowest overpotential value as shown in **Table 1**. However, the presence of *Dioscorea opposita* flour media still provides a recognized value if wastewater from *Dioscorea opposita* flour industry was utilized later on instead of freshwater.

The addition of *Dioscorea opposita* flour media had a negative tendency with lowering stainless steel electrode activity. It is due to the covering of the electrode active site (Pons *et al*., 2011) which disrupts the adsorption and desorption process simultaneously. In general, water splitting into hydrogen and oxygen gas consists of adsorption and desorption on the electrode surface area as described by Volmer–Heyrovsky reaction mechanisms. Furthermore, the electrode activity is linear with hydrogen and oxygen gas production in the water-splitting process.

The efficiency of hydrogen production could be increased by water electrolysis at high temperatures (Doenitz *et al*., 1980; Ferrero *et al*., 2013; Petipas *et al*., 2013) with high activity electrodes (Demir *et al*., 2018; Li *et al*., 2014). Regarded as high activity electrode, stainless steel could be implemented in higher electrolysis temperatures. However, the study only covered room temperature conditions of water electrolysis.

Hydrogen gas is categorized as alternatively renewable fuel and environmentally friendly due to no-pollutant production. Therefore, the study on hydrogen gas production is very helpful for the development of science and technology particularly on renewable energy sources (Jeremiasse *et al*., 2011). The energy issues need to be solved with the sophisticated study of science and technology.

5. CONCLUSION

The cyclic voltammogram of the stainless steel in various concentrations of the media could be used to study the activity of the stainless steel electrode on the splitting of the water molecule to produce hydrogen and oxygen gases. The activity of the electrode and the energy consumption was increased of 29 and 23% respectively by adding 3 gram of the media. However, regarding energy consumption, no media addition was the lowest. Moreover, the result of the study can conclude that the utilization of wastewater from *Dioscorea opposita* flour industry is still beneficial to produce hydrogen gas instead of using freshwater.

6. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. The authors confirmed that the paper was free of plagiarism.

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