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Electrochemical Production of Hydrogen in Fermented Flour by Stainless Steel Electrode

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Hydrogen gas production with an electrochemical method requires more energy. This research aimed to determine the efficiency of the electrolysis process in product and energy consumptions using stainless steel as a working electrode and various concentration of the fermented flour as the media. The fermented flour was prepared by fermentation of *Manihot utilissima* with *Monascus* sp. and characterized by infrared spectroscopy. The stainless steel was characterized by voltammetry, SEM-EDX, XRD and gas sorption analyzer. The results showed that stainless steel activity was decreased in the fermented flour because the surface of stainless steel was being covered. Moreover, addition of 0-2 g/L water fermented flour had relatively similar stainless steel activity. The cathodic current peaks were at -4.86×10^{-4} and -4.87×10^{-4} mA, respectively, for 0 and 2 g/L media. The processes had consumed the same energy with -0.0996 V of cathodic peak potential.

Keywords: Hydrogen gas, Stainless Steel, Fermented flour, Electrolysis.

INTRODUCTION

Hydrogen gas is a renewable energy, which is safe and green. It has a high octane number and high released energy. Hydrogen can be produced using the electrochemical method. The electrochemical process can solve many problems related to the analysis, synthesis, and identification of sample with issues regarding energy, especially renewable energy. Hydrogen gas production by water electrolysis had been studied by several authors [1-8]. Generally, water electrolysis has low efficiency in spite of product and energy demand [9]. To increase the production of hydrogen gas through the electrochemical method, some modification should be made. The adjustment could be related to the electrodes, batch solution modification, photovoltaic (PV) electrolysis, steam electrolysis and integrated system using membrane.

The stainless steel and combined metals or other materials have been conducted as a working electrode in water electrolysis to produce hydrogen gas [10-12]. The hydrogen evolution reaction on the binary electrodes (stainless steel/Fe-Co, stainless steel/Fe-Ni and stainless steel/Co-Ni) [13,14] and their voltammogram of stainless steel on water electrolysis in base solution have also been investigated. All these works showed that stain-less steel/Fe-Co-Ni electrode has higher activity than stainless steel. However, it is still interesting to use stainless steel as a working electrode because some studies even showed a positive result regarding hydrogen production. An addition of 3 g of *Dioscorea alata* flour can upgrade the hydrogen gas production as much 1.3 times using stainless steel as a working cathode [15]. Moreover, stainless steel has endured of corrosion and oxidation, less impurity, ease in treatment and relatively inex-pensive.

A modification of batch solution in the electrolysis process also improves efficiency. The curves of temperature *versus* time on the electrolysis of salt solutions in various market brands with carbon as the working electrode showed the multiple diverse in thermograms [16]. The water electrolysis with the addition of isotonic beverage both in aqueous or powder type had been studied, which resulted in low efficiency. It means that the electrochemical water decomposition is rather expensive [1]. The effects of various media on the water electrolysis had also been investigated [17-20]. Generally, efficiency of water electrolysis is still relatively low [21-23]. However, one of the potential flour, which is *Manihot esculenta* has not been studied. *Manihot esculenta* is abundant and inexpensive. The fermentation was conducted to cut the carbon bonds shorter and

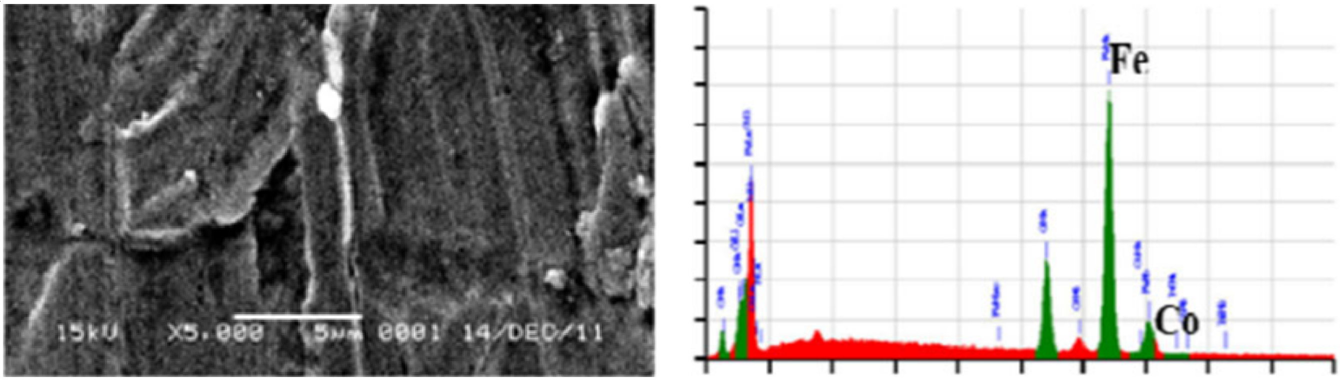

Fig. 1. SEM-EDAX spectrum of stainless steel

produced polar compounds. Longer carbon bonds significantly cause blocking in the electrolysis process.

In this work, an activity of the electrolysis process was studied by cyclic voltammetry. The composition of flour was analyzed by infrared spectroscopy, whereas an electrode was analyzed using X-ray diffraction (XRD), scanning electron micrograph-energy dispersive X-ray (SEM-EDX) and gas sorption analysis (GSA). Water electrolysis was conducted in base solution with the addition of 5 g $NaHCO_3$ per liter water and various concentrations of fermented flour. In this study, we used stainless steel as a working electrode, platinum as a counter electrode and Ag/AgCl as a reference electrode.

EXPERIMENTAL

All the chemicals were procured from Sigma-Aldrich and consist of 99.9 % purity. *Manihot esculenta* flour was purchased for the local market of Yogyakarta city, Indonesia.

General procedure: The electrolysis process used eDAQ EChem voltammeter (Australia) with the stainless steel as the working electrode, platinum as the counter electrode and Ag/AgCl as reference electrode. The base solution was prepared by adding 5 g $NaHCO_3$ into 1 L of distilled water. The various concentrations of the fermented flour were added in the solution (11 different systems). Each sample was electrolyzed at a scan rate of 50 mV/s.

Data analysis: A quantitative data of cathodic current peak and its potentials were measured by the voltammeter. The efficiency of the electrolysis process consisted of hydrogen productivity and energy consumed during the process were determined as follows:

$$\varepsilon = \frac{i_{c,media}}{i_{c,non\text{-}media}} \times 100\ \% \quad (1)$$

$$\Delta E = E_{experiment} - E_{theoretic} \quad (2)$$

where, ε, i_c and E refer to the hydrogen product efficiency, cathodic curent peak, and the potential of electrolysis process, respectively.

RESULTS AND DISCUSSION

Characterization of stainless steel: The surface and the composition of stainless steel were identified by SEM-EDAX (Fig. 1). The stainless steel contained ferrous and cobalt, while nickel was not detected (Table-1) [13]. Surface area (6.628 m^2/g), pore-volume (0.011 cc/g) and pore radius (15.318 Å) of stainless steel were determined by gas sorption analyzer. The XRD spectrum of stainless steel is illustrated in Fig. 2.

TABLE-1
COMPOSITION OF STAINLESS STEEL
USED AS WORKING ELECTRODE

Element	Mass (%)
Fe	80.11
Co	0.05
Ni	0

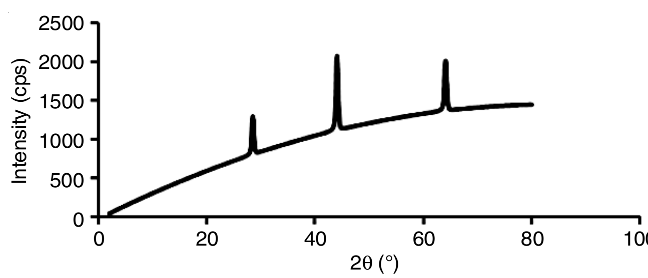

Fig. 2. XRD spectrum of stainless steel

Cyclic voltammetry: Based on voltammograms, especially the cathodic current peak (Figs. 3 and 4), it can be concluded that the activity of stainless steel was decreased in the fermented flour (Table-2). The molecules of fermented flour covered the surface active sites of electrode, and the hydrogen ions of adsorption were reduced. An activity of the system with 2 g of the fermented flour per liter water is relatively similar to the system

TABLE-2
CATHODIC CURRENT PEAK AND POTENTIAL

Flour addition (g/L)	i_c (mA)	E (V)
0	-4.87×10^{-4}	-9.96×10^{-1}
1	-4.72×10^{-4}	-9.96×10^{-1}
2	-4.86×10^{-4}	-9.96×10^{-1}
3	-4.76×10^{-4}	-9.96×10^{-1}
4	-4.47×10^{-4}	-9.96×10^{-1}
5	-4.59×10^{-4}	-9.96×10^{-1}
6	-4.72×10^{-4}	-9.96×10^{-1}
7	-4.61×10^{-4}	-9.96×10^{-1}
8	-4.32×10^{-4}	-9.96×10^{-1}
9	-4.70×10^{-4}	-9.96×10^{-1}
10	-4.10×10^{-5}	-9.96×10^{-1}

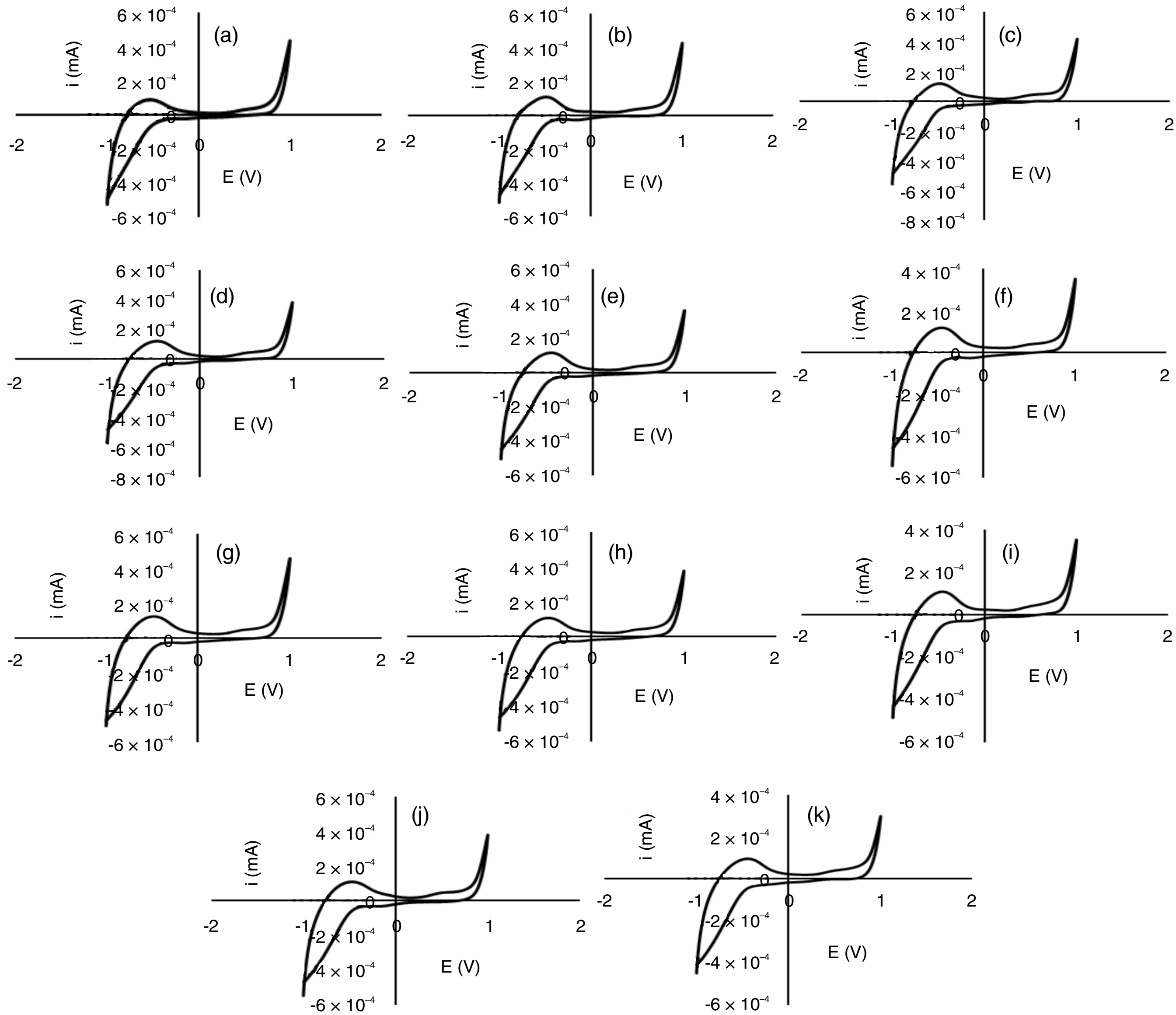

Fig. 3. Voltammograms of stainless steel on water electrolysis in the fermented flour 0-10 g/L addition (a-k) and base condition

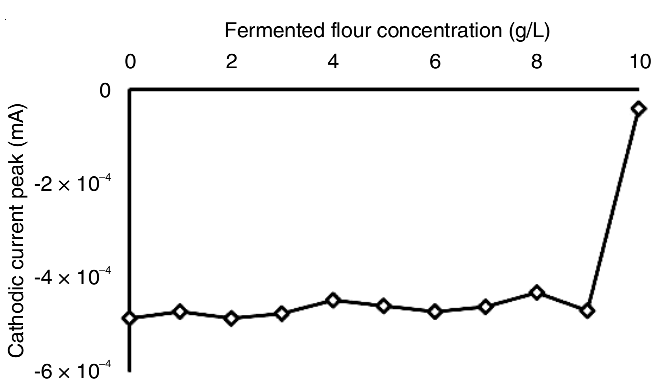

Fig. 4. Cathodic current peak

without fermented flour with the cathodic current peak at -4.86 × 10^{-4} and -4.87 × 10^{-4} mA, respectively. It also consumed the same energy in various concentration of the fermented flour with its potential at - 0.0996 V. The molecules of corn starch and mocaf (modified cassava flour) also covered the surface active sites of the electrode.

A covering of surface area of electrode can obstruct hydrogen ions adsorption and desorption so that water electrolysis decreased. It was shown by the declining cathodic current peak in flour media. In flour media, hydrogen and hydroxyl ions in the solutions become impaired to be moved. A moving of hydrogen ions into the cathode also become impaired, so that adsorption and desorption of hydrogen ions on the surface of electrode were decreased and the evolution reaction of hydrogen moved slower.

Conclusion

The present work had successfully performed the water electrolysis using stainless steel as a working electrode and fermented flour as the media. It showed that the activity of stainless steel decreased because there was a covering process at the electrode surface area. The addition of 2 g/L fermented flour had similar stainless steel activity compared to the system without fermented flour at – 4.86 × 10^{-4} and – 4.87 × 10^{-4} mA, respectively, for 0 and 2 g/L. The systems consumed the same amount of energy with its potential at – 0.0996 V.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

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