

## COMPARISON STUDY OF STAINLESS STEEL CYCLIC VOLTAMMOGRAMS IN VARIOUS NATURAL MEDIA ADDITION: PRODUCT AND VOLTAGE EFFICIENCY

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**ABSTRACT:** The cyclic voltammogram is widely used to analyse the electrolysis process. The use of various media, namely rambutan seed flour (*Nephelium lappaceum*), mango seed flour (*Mangifera indica*), breadfruit leaf powder (*Artocarpus altilis*), peria extract (*Momordi charantia*) and aloe vera extract (*Aloe vera*), in this study is to deliberately mimic the occurrence of those media in wastewater produced by several industries. The electrolysis analysis on the presence of several media would minimize the preparation steps on wastewater utilization for generating hydrogen as renewable energy. The research looks at the potential of wastewater as the raw material for the electrolysis process. In this research, stainless steel cyclic voltammograms were studied on water electrolysis. The electrolysis was done in base solution and adding various media, such as rambutan seed flour (*Nephelium lappaceum*), mango seed flour (*Mangifera indica*), breadfruit leaf powder (*Artocarpus altilis*), peria extract (*Momordi charantia*) and aloe vera extract (*Aloe vera*) in various concentrations, 0 - 10 g per liter of water. By reviewing the activity of a stainless steel electrode to decompose water molecules, the media generally caused the occurrence of covering by relatively large molecules around the electrode surface, resulting in decreased activity of the stainless steel electrodes. The optimum condition occurred with the addition of breadfruit leaf powder in all treatments with similar electrode activity as much as 1.68. The result could be implemented in a wastewater electrolysis processes containing the media to generate hydrogen gas.

**ABSTRAK:** Voltammogram berkisar banyak digunakan bagi menganalisis proses elektrolisis. Dalam kajian ini pelbagai jenis media telah sengaja digunakan seperti tepung biji rambutan (*Nephelium lappaceum*), tepung biji mangga (*Mangifera indica*), serbuk daun sukun (*Artocarpus altilis*), ekstrak peria (*Momordi charantia*) dan ekstrak lidah buaya (*Aloe vera*), bagi memimik terjadinya media-media tersebut dalam sisa air buangan yang terhasil daripada beberapa industri. Analisis elektrolisis pada pelbagai media dapat mengurangkan langkah-langkah persiapan pada penggunaan sisa air bagi menghasilkan hidrogen sebagai tenaga boleh baharu. Penilitian kajian ini bertumpu pada potensi sisa air sebagai bahan kasar bagi proses elektrolisis. Kajian ini adalah tentang elektrolisis air voltammogram berkisar pada keluli tahan karat. Proses elektrolisis telah dilakukan pada larutan dasar dan dengan menambah pelbagai media, seperti tepung biji rambutan (*Nephelium lappaceum*), tepung biji mangga (*Mangifera indica*), serbuk daun sukun (*Artocarpus altilis*), ekstrak petola (*Momordi charantia*) dan ekstrak lidah buaya (*Aloe vera*) dalam pelbagai kepekatan, 0 - 10 gram pada setiap liter air. Penurunan aktiviti elektrod keluli tahan karat telah disebabkan oleh aktiviti elektrod keluli tahan karat yang mengurai molekul air dan diliputi molekul-molekul besar pada permukaan

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elektrod. Keadaan optimum telah berlaku dengan penambahan serbuk daun sukun pada semua rawatan dengan aktiviti elektrod serupa sebanyak 1.68. Dapatan kajian dapat digunakan dalam proses elektrolisis sisa air yang mengandungi media bagi menghasilkan gas hidrogen.

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**KEYWORDS:** *voltammogram; stainless steel; media; electrode activity; efficiency*

## 1. INTRODUCTION

The voltammetry method is favourable for synthesis, analysis, and characterization or application, namely linear and cyclic voltammetry. In cyclic voltammetry, the same potential was applied on continuous time measurement for the electric current recording [1-5]. Furthermore, an electric current is plotted against a potential (Voltammogram) which can be used as a basis for analysing samples. For the same sample measured under similar conditions, it will have a similar voltammogram. Otherwise, when the modified state is applied, it will give a different voltammogram. The electrolysis of water will provide a typical cyclic voltammogram with differences occurring for electrodes and media changes. Hence, it could be used to study the efficiency of the electrolysis process.

Water molecules can be decomposed to hydrogen and oxygen gases by electrolysis. The electrolysis process depends on the type of electrolyte, the type of electrode, current, and time used [6-10]. Hydrogen is a well-known renewable energy source with its environmentally friendly property. Hydrogen gas production by electrolysis of water has relatively low-efficiency [11]. Therefore, it is necessary to strive for a condition of electrolysis of water with high efficiency in hydrogen gas production and voltage efficiency. To produce safe, environmentally friendly, and cheap hydrogen it needs an effort to meet energy demand, given the increasing rarity of fossil fuels and their non-renewability.

One of the methods to increase efficiency is through modification of the electrodes. The preparation, characterization, and application of stainless steel electro-catalyst electrodes for producing hydrogen gas had been reported by Isana et al. [12]. The voltammogram pattern of the stainless steel/Fe-Co-Ni electrolysis in base solution had been analysed by [13] and the reaction of hydrogen evolution in the stainless steel/Fe-Co-Ni electrode [14] showed that the ternary electrode has relatively better catalytic activity than binary and single electrodes. The reaction of hydrogen evolution in Fe-Co/s, Fe-Ni/s and Co-Ni/s electrodes [15] showed that stainless steel coated electrodes with binary metals have relatively better catalytic activity than stainless steel electrode. Meanwhile, Islam [16] evaluated the surfaces of Fe-Ni films on various coating bath media and concluded the morphology that is characterized by a coarse-grained and non-smooth surfaces with the presence of micro-cracks on it is superior. Other studies by Hairin et al. [17] and Salim [18] showed that high surface area is produced from the coating using the electrodeposition method.

Another method to increase efficiency is conducted on the batch solution manipulation of water electrolysis. The temperature thermogram against the time of electrolysis of various brands of salt solution using carbon electrodes showed the diversity of thermograms, which differed with each brand that had been studied by Isana [19]. Another study on well water from various places with stainless steel electrodes indicated that each well water has different electrolysis behaviour [20]. Furthermore, the splitting of water molecules in a cornstarch medium had been reported, as well as in the medium of mocaf [21], in the *Ipomoea batatas* L flour medium [22], in dahlia bulbs flour [23, 24], in the bitter melon medium [25], and in mango

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seed flour [26] showing that there was covering at the surface of the electrode by the flour. Both the production of hydrogen and catalytic activity were relatively dependent on the media. The modification of batch solution can be beneficial on either improving the quality of water electrolysis or utilizing the wastewater of several industries containing several media.

To study the effect of media addition in the water electrolysis process, research was carried out on the electrolysis of water in base solutions by using stainless steel electrodes in various media. The media used in this research were rambutan seed flour (*Nephelium lappaceum*), mango seed flour (*Mangifera indica*), breadfruit leaves powder (*Artocarpus altilis*), peria extract (*Momordi charantia*) and aloe vera extract (*Aloe vera*). The major chemical compositions in the media from various studies are described in Table 1 and illustrated in Fig. 1. The problem formulation is (1) how does the activity of the stainless steel electrode affect the process of decomposition of water in various media based on the cyclic voltammogram? (2) How does media concentration affect the decomposition of a water molecule? (3) What is the value of the decomposing water molecule to produce hydrogen and oxygen gases in various media at the optimum condition?

Table 1: Major composition of media in water electrolysis using stainless steel

Media	Carbohydrate	Fatty acids	Crude protein	Amylose	Reference
Rambutan Seed Flour	87.04%	-	10.07%	32.14%	[27]
Mango Seed Flour	64.23%	12.00%	4.95%	-	[28]
Breadfruit leaves powder	50.00%	-	22.45%	-	[29]
Peria extract	-	-	18.02%	-	[30]
<i>Aloe vera</i> extract	61.68%	-	11.21%	-	[31]

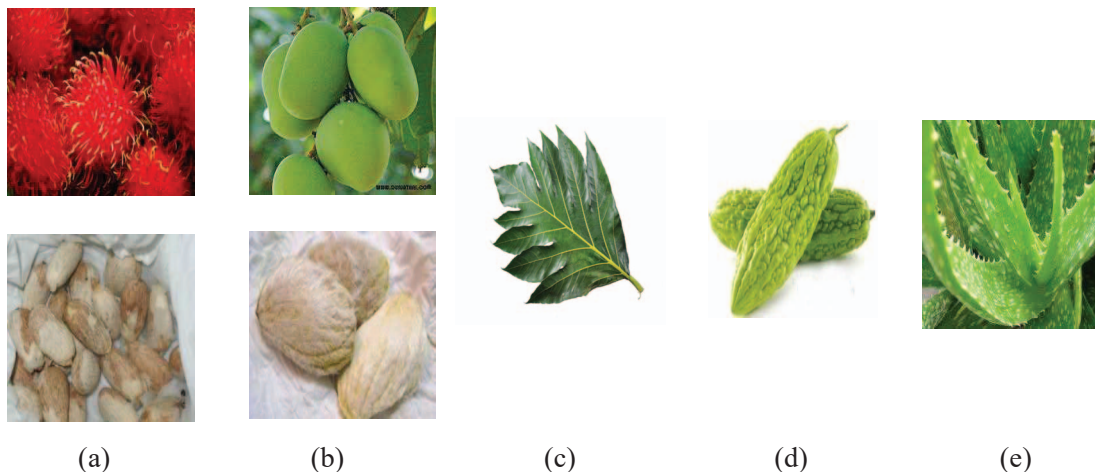


Fig. 1: (a) Rambutan and seed, (b) mango and seed, (c) breadfruit leaf, (d) peria and (e) *Aloe vera*.

## 2. MATERIALS AND METHODOLOGY

The equipment used here included glassware for preparation, an electrolysis tube, and a eDAQ EChem voltammeter. The materials used were nitric acid, acetone, and NaHCO<sub>3</sub> (Merck). Other materials such as stainless steel grades S-430 (thickness 1.2 mm, width 3 mm,

and length 110 mm), platinum electrodes, and Ag/AgCl electrodes were equipped as part of the electrolysis apparatus. The solvents, such as distilled water and aquabides, were produced locally in laboratory, while the media of rambutan seed flour, mango flour, breadfruit powder, peria extract, and *Aloe vera* extract were prepared and extracted from the local market. Several processes such as rinsing, drying, size reduction, and 100-mesh screening were used in the flour production of the media. Meanwhile, aloe vera extract was obtained by crushing the raw material using a blender followed by a filtration process.

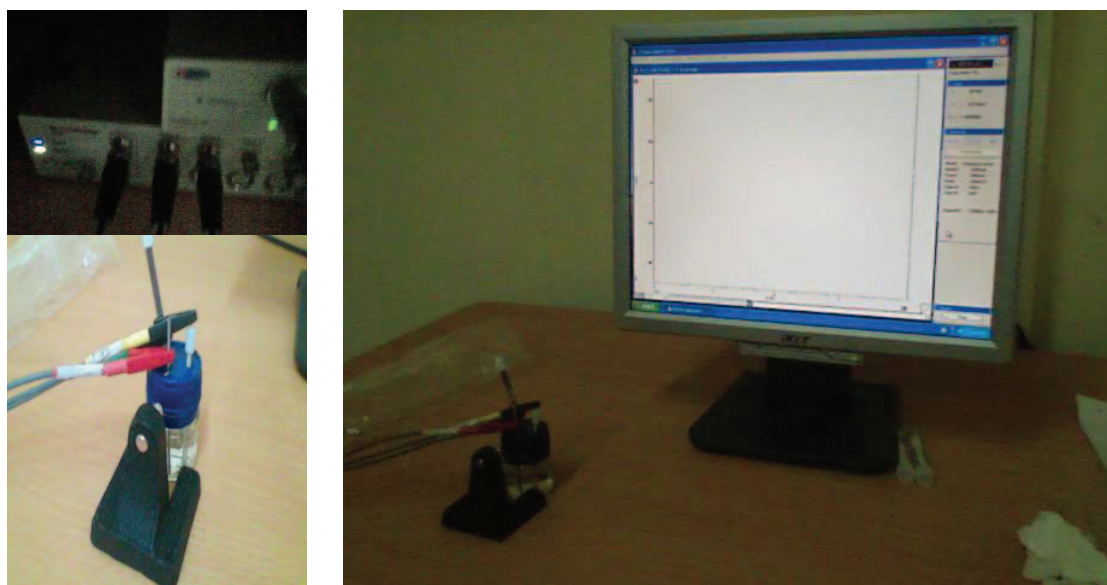


Fig. 2: eDAQ EChem voltammeter equipment in this study.

$\text{NaHCO}_3$  (5 g) was poured into one litre of water to make a base solution of mother liquor. Mother solution was added with each media with various concentrations under constant stirring for 1 hour. The concentration of the media varied from 0 to 10 g per 1 liter of water. Electrolysis of water was carried out by using stainless steel electrodes and various media. Meanwhile, the eDAQ EChem voltammeter (Fig. 2) was used to analyse the voltammetry during the electrolysis of water using multiple media. Furthermore, cyclic voltammetry was conducted twice for each sample to ensure data reliability. The eDAQ EChem have recorded the value of anodic-cathodic peak current and anodic-cathodic peak potential of the cyclic voltammogram data file experiment, which was further analysed to gain production efficiency and voltage efficiency. Production efficiency was calculated based on a comparison of the cathodic current peak with or without media, as shown in Eq. 1. Meanwhile, voltage efficiency was compared; observed as the voltage at the cathodic peak condition, for every treatment and the treatment without media as shown in Eq. 2. Furthermore, the electrolysis activity is expressed in Eq. 3 as comparing product efficiency and voltage efficiency.

$$\text{Product Efficiency} = \frac{I_{\text{with media}}}{I_{\text{without media}}} \times 100\% \quad (1)$$

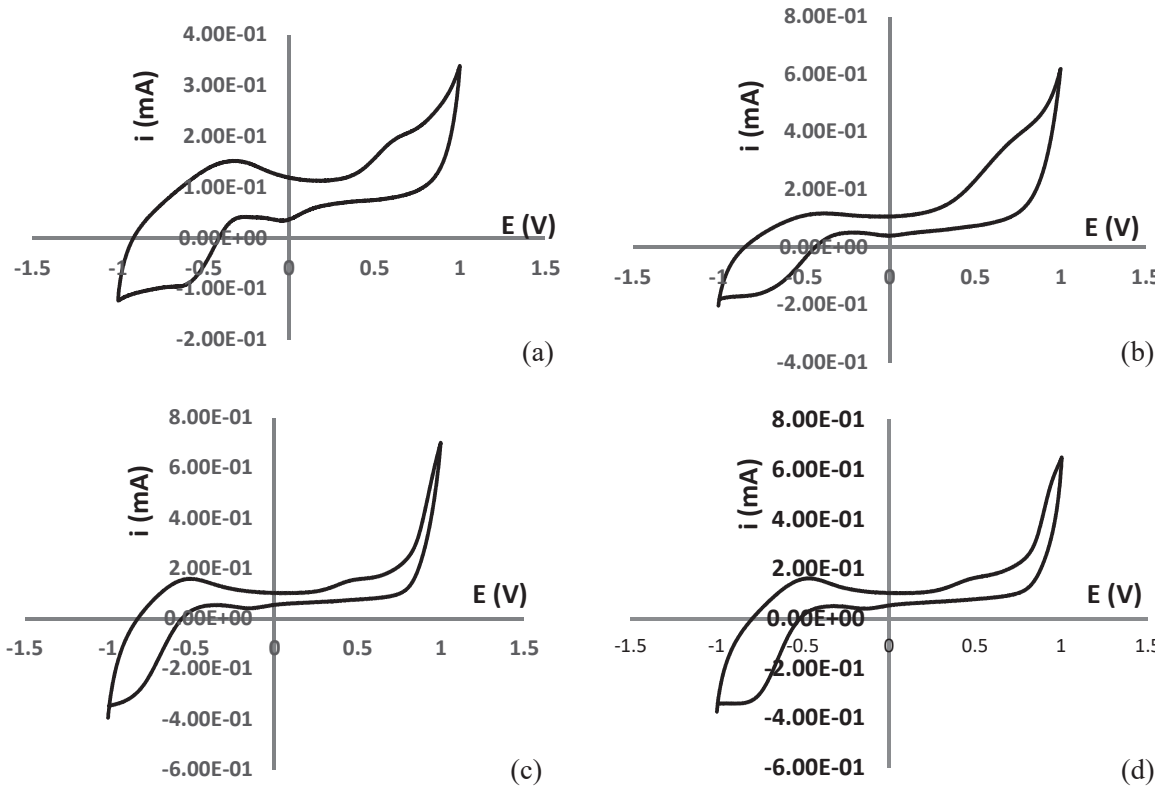
$$\text{Voltage efficiency} = \frac{\text{Operating voltage}}{\text{Thermodynamical voltage}} \quad (2)$$

$$\text{Activity of electrolysis} = \frac{\text{Product efficiency}}{\text{Voltage Efficiency}} \quad (3)$$

where thermodynamic voltage is 1.229 V at standard temperature and pressure.

### 3. RESULTS AND DISCUSSION

The stainless steel voltammogram in various media can be seen in Fig. 3. Based on the stainless steel cyclic voltammogram, the cathodic current peak and potential for each system of mass of media versus the efficiency of products are presented in Fig. 4 and voltage efficiency in Fig. 5 in various media such as rambutan seed flour, mango seed flour, breadfruit leaves powder, peria extract, and *Aloe vera* extract. The efficiency of hydrogen product and the voltage efficiency in various media from the cyclic voltammogram are summarized in Table 2. Meanwhile, product efficiency and voltage efficiency also were drawn in Figs. 4 and 5 to compare influences with each other. Furthermore, the activity of electrolysis was shown in Table 3 with the comparison of product efficiency and voltage efficiency in various media. From voltage efficiency, we can calculate the product efficiency using a comparison of voltage efficiency with or without media in every treatment.





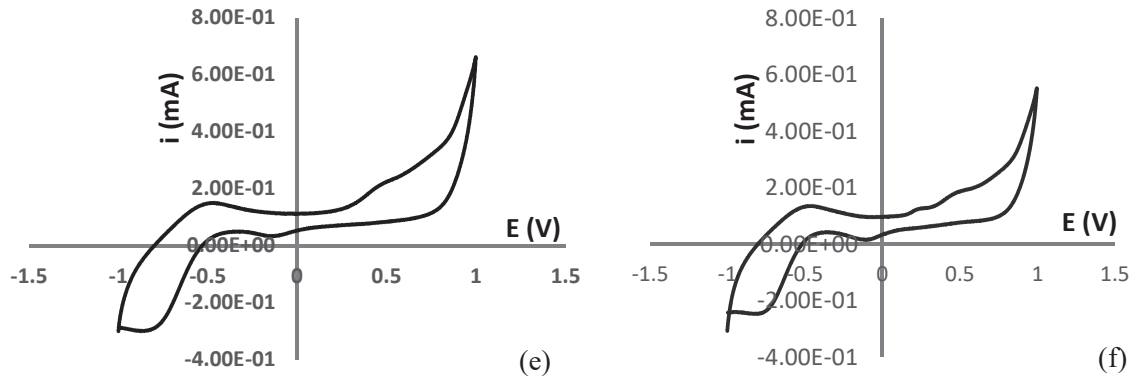


Fig. 3: Cyclic Voltammogram of stainless steel in various media: (a) rambutan seed flour, (b) mango seed flour, (c) breadfruit leaves powder, (d) peria extract, (e) *Aloe vera* extract, and (f) without media.

Tabel 2: The efficiency of hydrogen product and voltage efficiency in various media

No.	System	Product efficiency (%)					Voltage efficiency (%)				
		RSF	MSF	BLP	PE	AVE	RSF	MSF	BLP	PE	AVE
1	0 g	100.0	100.0	100.0	100.0	100.0	67.4	59.2	59.6	59.3	59.8
2	1 g	74.3	46.6	97.4	61.6	62.3	55.2	48.7	58.0	58.6	60.0
3	2 g	69.7	34.8	96.3	38.1	58.3	53.5	44.7	57.4	57.7	59.1
4	3 g	49.6	35.5	100.8	53.2	51.0	54.4	43.8	60.0	58.7	59.7
5	4 g	59.8	30.8	102.2	56.5	48.4	53.5	43.9	60.9	58.7	59.5
6	5 g	72.7	36.1	98.9	55.7	40.2	53.5	47.0	58.9	56.1	59.6
7	6 g	67.4	34.0	95.0	55.1	36.2	55.2	46.6	56.6	56.6	59.2
8	7 g	68.7	26.7	98.1	21.3	36.0	54.4	50.7	58.4	56.1	59.2
9	8 g	53.4	30.4	95.6	19.5	22.8	53.5	47.2	57.0	54.4	59.1
10	9 g	40.7	36.7	99.5	48.5	25.5	54.4	46.3	59.2	53.6	59.2
11	10 g	40.6	35.6	96.5	35.8	27.7	53.5	47.4	57.4	49.9	59.3

RSF: rambutan seed flour, MSF: mango seed flour, BLP: breadfruit leaves powder, PE: peria extract, and AVE: *Aloe vera* extract

Cyclic stainless steel voltammograms in various media can be used to study the activity of the stainless steel electrode on decomposition of water molecules to form hydrogen and oxygen gases. The comparison between product gained, and the voltage efficiency is the best method to represent the activity of the stainless steel electrode on decomposition of water molecules to form hydrogen and oxygen gases. Randles-Sevcik's equation describes that the peak current for a reversible system is affected by electron stoichiometry ( $n$ ), electrode area ( $A$ ,  $\text{cm}^2$ ), diffusion coefficient ( $D$ ,  $\text{cm}^2/\text{s}$ ), concentration ( $\text{mol}/\text{cm}^3$ ), and scan rate ( $v$ ,  $\text{V}/\text{s}$ ) as shown at Eq. 5. Thus, the concentration of the product is affecting the peak current of cyclic voltammetry. Voltage efficiency is the value of energy used to produce hydrogen and oxygen gas compared to the initial condition without any addition of the media.

$$I_p = (2.69 \times 10^5)n^{3/2}AD^{1/2}Cv^{1/2} \quad (5)$$

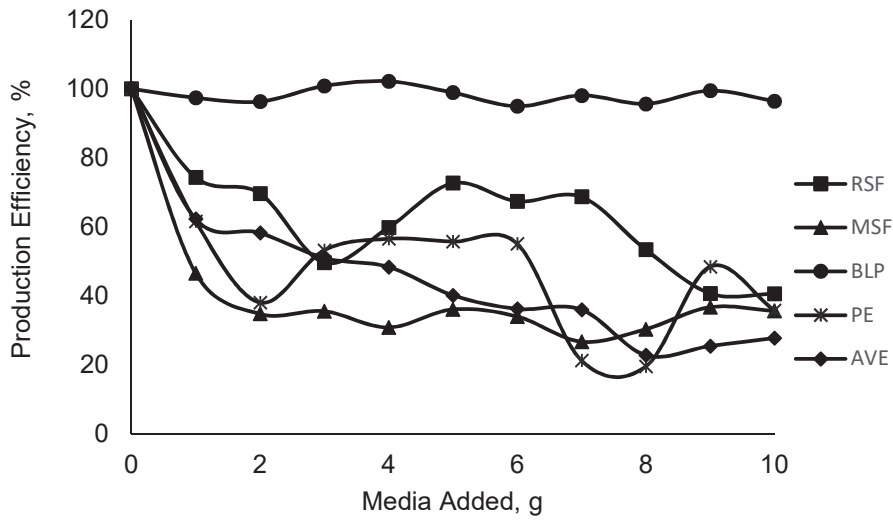


Fig. 4: The efficiency of hydrogen product of various media.

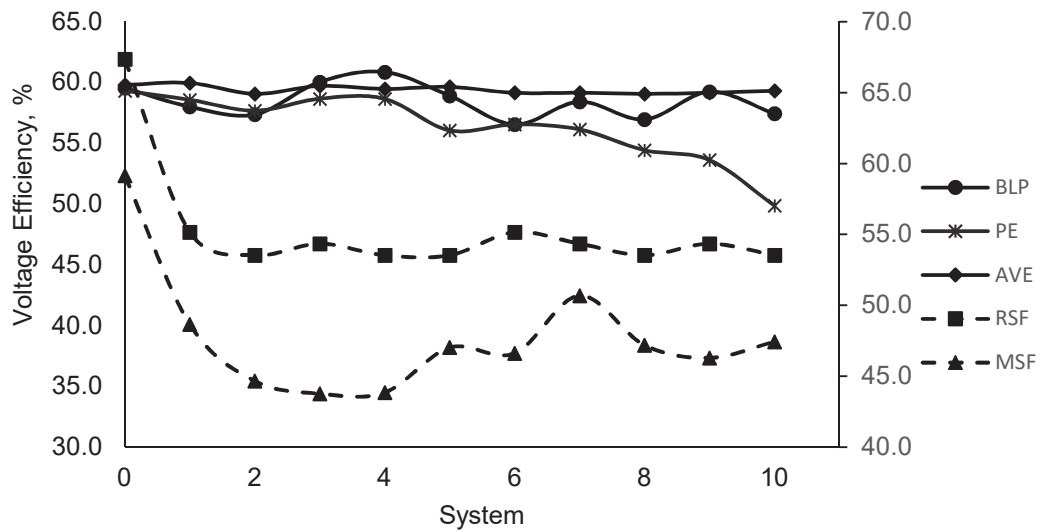


Fig. 5: The voltage efficiency of various media, solid and dotted line indicated major and minor y-axis respectively.

Regarding voltage efficiency, the addition of rambutan seed flour and mango seed flour showed decreasing result. Meanwhile, the other media did not significantly impact voltage efficiency. The result of the hydrogen product yield, ranked from relatively high efficiency to relatively small efficiency, is as follows: breadfruit leaves powder, rambutan seed flour, peria extract, *Aloe vera* extract, and mango seed flour. When viewed from energy consumption, illustrated with voltage efficiency, the sequence becomes: mango seed flour, rambutan seed flour, peria extract, breadfruit leaf powder, and *Aloe vera* extract. The most unfavourable

medium to decompose water molecules into hydrogen and oxygen gases was the *Aloe vera* extract.

From Table 3, it can be concluded that the bigger the value, the better the activity of the stainless steel electrode is. The calculation using least significant difference was conducted to analyse the significance of the activity of electrolysis value. In general, the media caused the covering surface of the electrode because of its relatively large molecules, resulting in decreased activity of the electrode, as presented in Fig. 6 (b). From Eq. 4, it can be shown that the presence of media can disturb the diffusivity ( $D$ ,  $\text{cm}^2/\text{s}$ ) because the media are covering the electrode. Interestingly, the addition of Breadfruit Leaves Powder gave an unusual trend, as shown in Fig. 6 (a). Those graph tendencies are strongly believed to be the result of the polymer structure in the media that had not covered the electrode. The polymer occurrence in every media affects the interaction between the surface of the electrode and the polymer itself influences the electrode activity.

Tabel 3: Activity of electrolysis in various media

No	System	Activity of Electrolysis				
		RSF	MSF	BLP	PE	AVE
1	0 g	1.49 <sup>b</sup>	1.70 <sup>a</sup>	1.68 <sup>a</sup>	1.69 <sup>a</sup>	1.68 <sup>a</sup>
2	1 g	1.35 <sup>b</sup>	0.96 <sup>b</sup>	1.68 <sup>a</sup>	1.06 <sup>b</sup>	1.04 <sup>b</sup>
3	2 g	1.31 <sup>b</sup>	0.78 <sup>c</sup>	1.68 <sup>a</sup>	0.66 <sup>c</sup>	0.99 <sup>b</sup>
4	3 g	0.92 <sup>c</sup>	0.82 <sup>c</sup>	1.68 <sup>a</sup>	0.91 <sup>c</sup>	0.86 <sup>c</sup>
5	4 g	1.12 <sup>b</sup>	0.71 <sup>c</sup>	1.68 <sup>a</sup>	0.97 <sup>b</sup>	0.82 <sup>c</sup>
6	5 g	1.36 <sup>b</sup>	0.77 <sup>c</sup>	1.68 <sup>a</sup>	1.00 <sup>b</sup>	0.68 <sup>c</sup>
7	6 g	1.23 <sup>b</sup>	0.73 <sup>c</sup>	1.68 <sup>a</sup>	0.98 <sup>b</sup>	0.62 <sup>c</sup>
8	7 g	1.27 <sup>b</sup>	0.53 <sup>c</sup>	1.68 <sup>a</sup>	0.38 <sup>c</sup>	0.61 <sup>c</sup>
9	8 g	1.00 <sup>b</sup>	0.65 <sup>c</sup>	1.68 <sup>a</sup>	0.36 <sup>c</sup>	0.39 <sup>c</sup>
10	9 g	0.75 <sup>c</sup>	0.80 <sup>c</sup>	1.68 <sup>a</sup>	0.91 <sup>c</sup>	0.44 <sup>c</sup>
11	10 g	0.76 <sup>c</sup>	0.76 <sup>c</sup>	1.68 <sup>a</sup>	0.72 <sup>c</sup>	0.47 <sup>c</sup>

RSF: rambutan seed flour, MSF: mango seed flour, BLP: breadfruit leaves powder, PE: peria extract, and AVE: *Aloe vera* extract  
 a,b, and c show significance group.

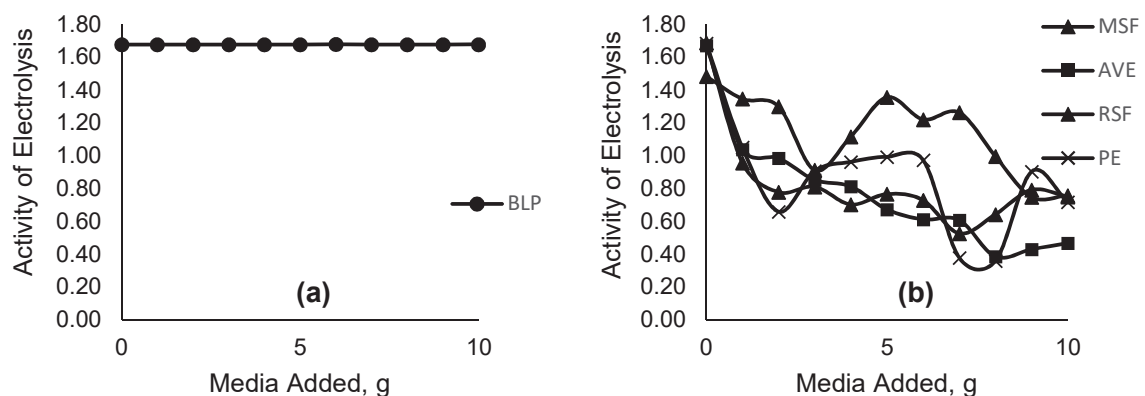


Fig. 6: The activity of electrolysis in various media; (a) unusual trend and (b) usual trend.



The optimum condition occurred when the electrolysis activity is highest. It is obtained when the production efficiency is high, and the voltage efficiency is low. The higher the cathodic current peak, the higher hydrogen production is, so that the higher the activity of the electrode; and the lower the potential, the lower the voltage efficiency. That is the best condition to decompose water molecules into hydrogen and oxygen gases. Therefore, the optimum condition from this research occurred with the addition of breadfruit leaves powder for which the electrolysis activity was constant around 1.68.

#### 4. CONCLUSION

The activity of stainless steel electrodes in the decomposition of a water molecule into hydrogen and oxygen gases in various media varied greatly. The optimum conditions for water molecule decomposition into hydrogen and oxygen gases were achieved by adding breadfruit leaves powder at every system with similar activity of electrolysis around 1.68. The addition of various media, regularly, could not improve the electrode activity, but the addition of breadfruit leaves powder could stabilize the electrode activity. The results could give an illustration and initial data to the generalization of hydrogen gas using the electrolysis process in wastewater mainly containing flour media.

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