

KING MONGKUT'S INSTITUTE OF TECHNOLOGY
LADKRABANG
FACULTY OF ENGINEERING
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01366314 CHEMICAL ENGINEERING PROJECT

ELECTROLYZED WATER PRODUCTION BY ELECTROLYSIS

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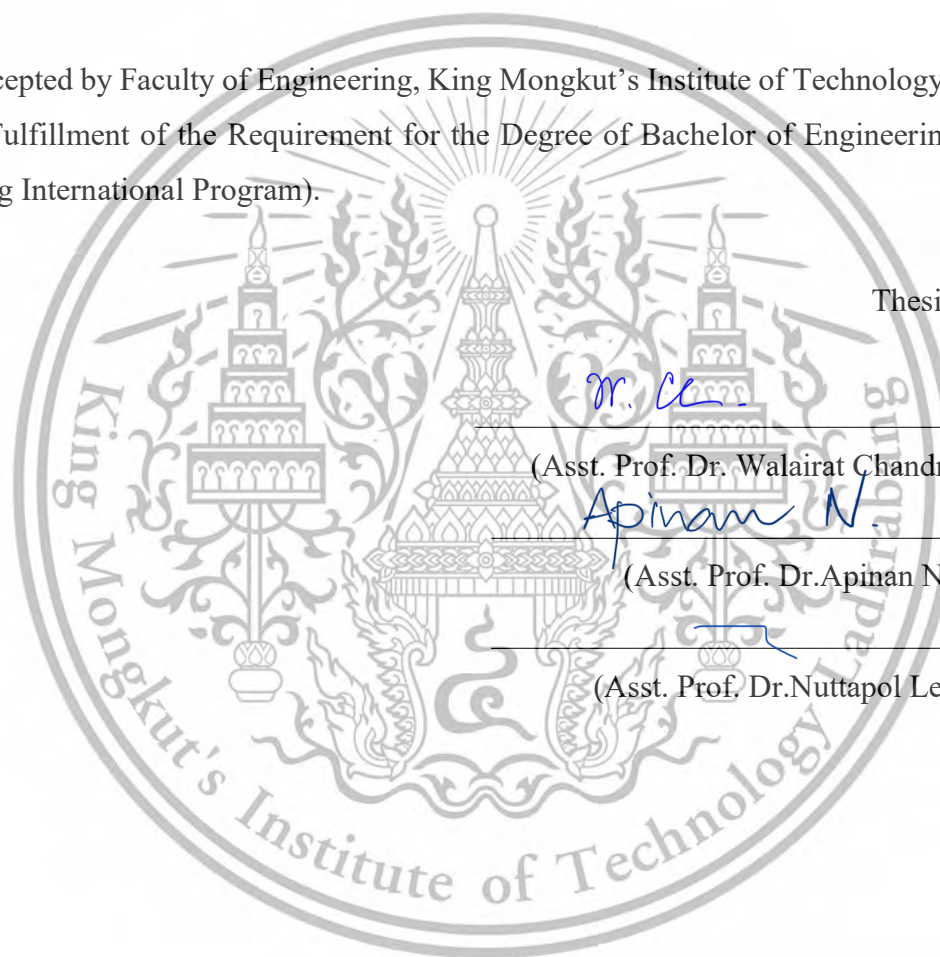
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ABSTRACT

This report indicates the method to develop electrolyzed water by using electrolysis method and the condition of the storage for the ideal solution. As the electrolyzed water contains hypochlorous acid which the property of it can disinfect pathogens by ruining the cell wall and protein of the pathogens, electrolyzed water can be used as the disinfection. It is another choice of antiseptic which has more advantages than alcohol-based antiseptic. Electrolyzed water can be produced by mixing sodium chloride with distilled water and applying the electricity into the system by DC power supply. To indicate the efficacy of the electrolyzed water, some factors such as, pH, oxidation-reduction potential or ORP and chlorine concentration, need to be tested. Electrolyzed water should have pH value around 5-6.5. The value of oxidation-reduction potential should be more than 800 mV and lastly chlorine concentration value should be around 10-30 mg/l. From the experiment of storage of the electrolyzed water under different circumstance, the best storage type that the electrolyzed water should store in is the amber glass bottle under the dark circumstance with 7.13 pH, 170 mV of oxidation-reduction potential and 2 ppm of chlorine concentration. However, it still did not meet the criterial of the ideal electrolyzed water that can be used as the antiseptic.

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CHAPTER 1

INTRODUCTION

1.1 Background

In the past few years, the coronavirus disease has started to spread all around the world since 2019. The number of the infected people still increase every day. Not only the corona virus that spreads all around the world, but there are also many viruses that are in our daily life such as Hepatitis A and B, Influenzas etc. The antiseptic which is another name of electrolyzed water takes the important role in disinfect these viruses. The alcohol sanitizer has been widely used since the pandemic started. However, there are some disadvantages of alcohol sanitizer [5].

1. Using too much alcohol sanitizer may cause the irritation to skin, dry, cracked skin and redness.
2. The alcohol sanitizer lacks the potential in killing or disinfect some virus or bacteria, especially the virus that is the airborne virus that can spread in the air.
3. Ingestion of the alcohol can be the cause of serious injury and adverse health effects such as liver cirrhosis.
4. The property of the alcohol is flammability. It requires safety storage because it can ignite if there is a spark.

1.2 Objectives

- 1.2.1 To develop the method to produce the electrolyzed water by using the electrolysis method.
- 1.2.2 To measure the factors that are needed to test before using the electrolyzed water.
- 1.2.3 To find the ideal solution by discussing about the storage.

1.3 Project scope

- 1.3.1 The project studies different concentration of sodium chloride to optimize the electrolysis efficiency and the desired properties of the resulting of the electrolyzed water.
- 1.3.2 The project study the effect of sodium chloride concentration on the efficiency of the electrolyzed water by varying the concentration of sodium chloride in the range of 0.10% - 4.00%.
- 1.3.3 The project focuses on the factor that will affect the efficacy of the electrolyzed water such as chlorine concentration, pH, oxidation-reduction potential by vary the concentration of the sodium chloride when produced the electrolyzed water.
- 1.3.4 The project focuses on the types of the electrode that used in the experiments by looking at the result of the experiment, can determine whether the color changed or not and whether there was an impact on pH, oxidation-reduction potential, and the chlorine concentration.
- 1.3.5 The project focuses on the voltage that was used in the experiments by calculating it from the standard Gibb's energy of formation that was emitted from each electrode plate.
- 1.3.6 The project focuses on the conditions of the storage that will influence the chlorine concentration, pH, and oxidation-reduction potential of the electrolyzed water by collecting the results of the experiment every day for 5 days and after that every 3 days.

CHAPTER 2

THEORY AND LITERATURE REVIEW

2.1 An overview of electrolyzed water

An electrolyzed water (EW) is a sanitizer or a chlorine-based antiseptic. It is an environmentally friendly and effective disinfectant which is produced by electrolysis process of electricity and salt (sodium chloride, NaCl) [1]. Because it does not use hazardous chemicals or processes, electrolyzed water is recognized as a practical disinfectant [1][8]. Electrolyzed water (EW) has many of ideal disinfectant's desired effects, such as it is simple to use, low cost, with an excellent safety profile, and can be used to disinfect large areas quickly and with a broad range of bactericidal and virucidal effects [1]. Electrolyzed water is already used in many industries such as healthcare, food safety, agriculture, and for general sanitation purposes.

Electrolyzed water is a sanitizer that contains mostly hypochlorous acid (HOCl), their most effective oxidizing agent. Hypochlorous acid (HOCl) is one disinfectant that, when combined with adequate personal protective equipment (PPE), screening and social distancing procedures, hand washing, and high-volume evacuation suction, can aid in reducing not only COVID-19 transmission but also other viruses' transmission.

2.2 Systems for generating electrolyzed water

Electrolyzed water (EW) is generated in an electrolysis chamber using a dilute salt (NaCl) solution according to the equipment's instruction. Based on the electrolysis condition and the electrolyte, electrolyzed water can be categorized into three categories: acidic electrolyzed water (AEW), neutral electrolyze water (NEW), and basic or alkaline electrolyzed water (BEW) [8].

The acidic electrolyzed water is formed at the anode. Sodium ion (Na^+) and chloride ions (Cl^-) are separated from the salt in the anode and cathode chambers, resulting in hydroxide and hydrogen ions formation in the solution, as shown in Figure 1. Cl_2 , O_2 , HCl are generated when negatively charged Cl^- and OH^- ions move towards the oxidation anode. Positively charged hydrogen ions (H^+) are transported to the cathode and reduced by sodium hydroxide (NaOH) and hydrogen (H_2). As a result, two types of electrolyzed water can be produced simultaneously: acidic anode solution and basic cathode solutions [1][7].

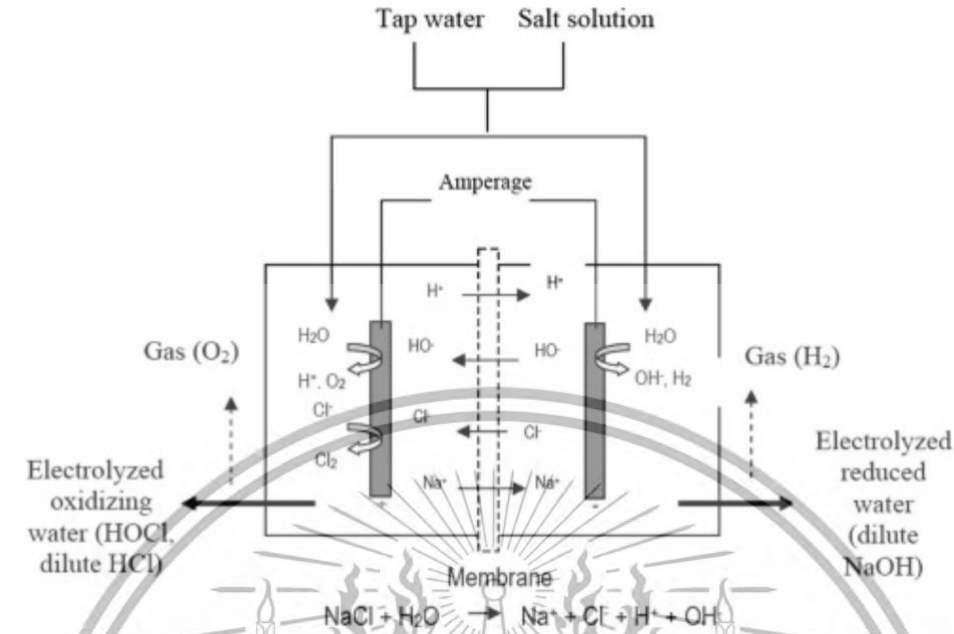


Figure 1: Generation of electrolyzed water (EW) [7].

Reactions at the anode;



Alkaline electrolyzed water is formed at the cathode of the electrolysis chamber where actions such as H⁺ and Na⁺ are transferred to the cathode where they take electrons and become hydrogen (H₂) or sodium hydroxide (NaOH) [1][7].

Reactions at the cathode;



2.3 Factors affecting electrolyzed water production and application efficiency

2.3.1 The effect of water hardness in the feed water characteristics

Water hardness is a significant parameter in electrolyzed water properties and disinfection efficiency. Water hardness is primarily caused by calcium and magnesium carbonates. Metal cations like magnesium and calcium can build up on the electrode because of water hardness. This will be the cause of the current density change in the electrolyte cell.

The hardness of the water affects the pH, the chlorine concentration (CC), and the oxidation reduction potential (ORP) of electrolyzed water. It will be influencing the disinfection efficiency [1] [6].

2.3.2 The effect of electrolyzed water pH on sanitizing efficiency

The pH of electrolyzed water (EW) plays a big role in how effective it is as a disinfectant [8]. Because oxidation reduction potential (ORP) values are a measure of two separate parameters, they have a weak correlation with chlorine concentration (CC) in electrolyzed water disinfection methods. The available chlorine is in its strongest form, HOCl, between pH 5 and 6.5 [1].

2.3.3 The effect of oxidation-reduction potential (ORP) on the efficiency of produced electrolyzed water

The oxidation reduction potential (ORP) is a measurement of sanitizer effectiveness in electrolyzed water. The oxidation reduction potential (ORP) is often used to determine the oxidizing or reducing potential of a water sample or electrolyzed water sample. When the oxidation reduction potential (ORP) value is high, that means there is lots of oxygen presented in electrolyzed water [1].

A high oxidation reduction potential (ORP) plays a major factor in electrolyzed water's disinfectant activity. The high oxidation reduction potential (ORP) causes oxidation in the outer layer of microorganisms, which leads to more oxidation reactions and finally it will breakdown the metabolic pathway in the organism's cell, which leads to the inactivation. Electrolyzed water's antimicrobial effectiveness is mostly determined by the concentration of hypochlorous acid (HOCl) and high oxidation reduction potential (ORP) values [1].

2.3.4 The effect of storage environment on electrolyzed water stability

The antimicrobial efficacy of electrolyzed water is affected by storage conditions due to the decomposition of the major antimicrobial component (HOCl) and evaporation of Cl₂ over time, especially when it is stored in open conditions. Due to the self-decomposition, the chlorine concentration (CC) is lost in electrolyzed water during storage under closed condition. The loss of chlorine concentration (CC) in closed environment is less than the loss of chlorine concentration (CC) due to the evaporation in open storage [1][2].

2.4 Theoretical decomposition voltage of NaCl solution

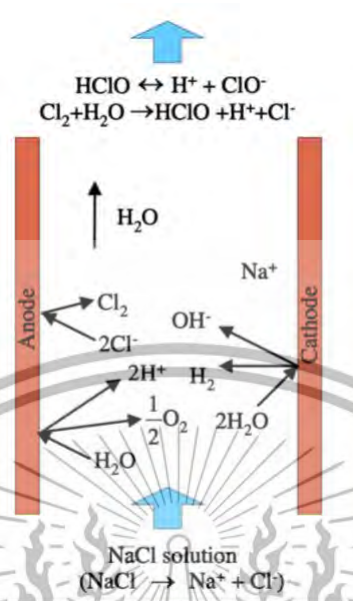


Figure 2: Hypochlorous acid (HOCl) production process [4].

In order to produce hypochlorous acid (HOCl) from a sodium chloride (NaCl) solution by electrolysis, Cl_2 has to be produced at the anode side, as shown in Figure 2. Before the experiment, it is important to theoretically verify the minimal voltage that required to produced Cl_2 . First, the standard electrode potentials of each electrode plate are estimated. Over this electrode potential, the electrolysis will start. The standard electrode plate is created by applying the standard Gibb's energy of formation. The standard Gibb's energy of formation, ΔG° , is emitted from each electrode plate as an electric energy [4].

$$-\Delta G^\circ = nF\Delta V \quad (6)$$

n is the number of electrons that involved in the reaction.

F is a Faraday's constant, $F = 9.65 \times 10^4 \text{ C/mol}$.

ΔV is the electric potential difference.

The reaction at an anode plate, Cl_2 is produced from Cl^- as shown in Equation (7).



Therefore, the electric potential difference, ΔV_{Cl_2} , require producing Cl_2 is determined by equation (6) because 1 mole of electron reacts with 1 mole of Cl^- .

$$\Delta V_{\text{Cl}_2} = -\frac{\Delta G^\circ_{[\text{Cl}^-]}}{nF}$$

$$\Delta V_{Cl_2} = -\frac{-131.2 \times 10^3}{1 \times (9.65 \times 10^4)} = 1.3596 \text{ V} \quad (8)$$

Here, $\Delta G^\circ(Cl^-) = -131.2 \text{ kJ/mol}$ at 25°C , 1 atmosphere.

On the other hand, at a cathode plate, H_2 is produced from H_2O as shown in equation (5).



The electric potential difference, ΔV_{H_2} , require to produce H_2 is estimate by Equation (6) as follows because 2 moles of electron react with 1 mole of H_2 .

$$\Delta V_{H_2} = -\frac{\Delta G^\circ_{[OH^-]}}{nF}$$

$$\Delta V_{H_2} = -\frac{-157.2 \times 10^3}{2 \times (9.65 \times 10^4)} = 0.8145 \text{ V} \quad (9)$$

Here, $\Delta G^\circ(OH^-) = 157.2 \text{ kJ/mol}$ at 25°C , 1 atmosphere. Therefore, the overall reaction needed to produce HOCl is shown in Equation (3).



As the result, the electric potential difference between anode and cathode electrode plates is estimated as follows.

$$\Delta V_{HOCl} = \Delta V_{Cl_2} + \Delta V_{H_2}$$

$$\Delta V_{HOCl} = 1.3596 + 0.8145 = 2.174 \text{ V} \quad (10)$$

The electric potential difference, called the decomposition voltage, $\Delta V_{HOCl} = 2.174 \text{ V}$ is required theoretically to produce hypochlorous acid (HOCl) [4].

2.5 Effect of acetic acid on electrolyzed water production

Acetic acid (CH_3OOH) is commonly used to control the pH of the hypochlorous acid solution produced by electrolysis of NaCl solution. This is because acetic acid is a weak organic acid that can act as a pH buffer, meaning it can resist changes in pH when small amounts of acids or bases are added. In the case of hypochlorous acid production, the electrolysis process generates both hypochlorous acid (HOCl) and hydroxide ions (OH^-), which can cause the pH of the solution to increase. By adding acetic acid to the solution, the hydroxide ions react with the acetic acid to form acetate ions (CH_3COO^-) and water, which helps to maintain the pH of the solution within the desired range. Additionally, acetic acid is relatively inexpensive and safe to handle, making it a popular choice for pH adjustment in industrial processes.

2.5.1 Advantages of using acetic acid to control the pH of hypochlorous acid

- Effect pH control: Acetic acid is a weak acid, which means it can effectively lower the pH of the hypochlorous acid solution without causing drastic changes or fluctuations.
- Cost effective: Acetic acid is relatively inexpensive and widely available, making it a cost-effective option for pH control.
- Easy to handle: Acetic acid is a liquid that is easy to handle and mix into hypochlorous acid solution.

2.5.2 Disadvantages of using acetic acid to control the pH of hypochlorous acid

- Strong odor: Acetic acid has a strong and unpleasant odor, which can be drawback in certain applications.
- Corrosive: Acetic acid is corrosive to some metals and can cause damage to equipment over time.
- Safety concerns: Acetic acid is considered hazardous and can be harmful if not handle properly. It can cause skin irritation, respiratory problems, and eyes damage if proper safety measures are not taken.
- Limited pH range: Acetic acid is only effective in lowering the pH of the hypochlorous acid solution to a certain extent, and it may not be effective in cases where a very low pH is required.

2.5.3 Calculation the volume of the acetic acid that used in the sample

We used the acetic acid to control the pH of the electrolyzed water that we produced. To calculate the volume of acetic acid (5%) that we needed to reduce the pH from 8.02 to 6.5 in a 600 ml NaCl 4% solution in the hypochlorous acid production by electrolysis process. We first need to determine the amount of hypochlorous acid needs to be neutralized. We can do this by using Henderson-Hasselbalch equation.

$$\text{pH} = \text{pK}_a + \log \frac{[\text{A}^-]}{[\text{HA}]} \quad (11)$$

Where, pH is the desired pH, which is 6.5, pK_a is the dissociation constant of hypochlorous acid, which is 7.53, $[\text{A}^-]$ is the concentration of the hypochlorite ion (which is formed when hypochlorous acid is deprotonated), and $[\text{HA}]$ is the concentration of hypochlorous acid. rearranging the equation, then we get:

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$$\frac{[\text{HA}]}{[\text{A}^-]} = 10^{(\text{pH}-\text{pKa})} \quad (12)$$

Then substitute the value we have:

$$\frac{[\text{HA}]}{[\text{A}^-]} = 10^{(6.5-7.53)} = 0.146$$

Since NaCl is a strong electrolyte, it will dissociate into Na^+ and Cl^- ions in solution and will contribute to the acidity or basicity of the solution. Therefore, we can assume that the initial pH of the NaCl solution is close to neutral (pH 7).

To calculate the initial concentration of hypochlorous acid in the solution, we can use the equation (13). This equation allows us to estimate the concentration of sodium chloride (NaCl) and the degree of dissociation (α).

$$[\text{HOCl}] = [\text{NaCl}] \times \alpha \quad (13)$$

Where $[\text{NaCl}]$ is the concentration of NaCl in the solution (in this experiment, we used 4%) and α is the degree of dissociation of hypochlorous acid, which can assume to be very small at pH 7. Assuming an alpha value of 0.01, we can calculate the initial concentration of hypochlorous acid. Then we get,

$$[\text{HOCl}] = 40 \text{ g/l} \times 0.01 = 0.4 \text{ g/l}$$

Now we need to calculate the amount of the hypochlorous acid that needs to be neutralized. Assuming that the final volume of the solution is still 600 ml after adding the acetic acid, we can calculate the amount of hypochlorous acid that needs to be neutralized by using the following equation:

$$\text{Moles of HOCl} = [\text{HOCl}] \times \text{volume of solution (in liters)} \quad (14)$$

$$\text{Moles of HOCl} = 0.4 \frac{\text{g}}{\text{l}} \times \frac{0.6 \text{ l}}{74.44 \text{ g/mol}} = 0.0051 \text{ mol}$$

To neutralize this amount of hypochlorous acid, we need an equal number of moles of acetic acid that is the 0.0051 mol. In this experiment, the concentration of acetic acid that we used is 5%. We can use the following equation to calculate the volume of acetic acid needed.

$$\begin{aligned} \text{Moles of acetic acid} &= \text{concentration} \times \text{volume of acetic acid (in liters)} \\ &\times \text{density} \times \text{molar mass of acetic acid} \end{aligned} \quad (15)$$

Then solving the volume of acetic acid, we get:

$$\text{Volume of acetic acid} = \frac{\text{moles of acetic acid}}{(\text{concentration} \times \text{density} \times \text{molar mass of acetic acid})} \quad (16)$$

$$\text{volume of acetic acid} = \frac{0.0051 \text{ mol}}{(0.05 \times 1.05 \frac{\text{g}}{\text{ml}} \times 60.05 \frac{\text{g}}{\text{mol}})} = 1.55 \text{ ml}$$

Therefore, we need to add 1.55 ml of acetic acid (5%) to the NaCl solution to reduce the pH from 8.02 to 6.5.



CHAPTER 3

METHODOLOGY

3.1 Experiment materials

3.1.1 Chemicals

- a. Sodium Chloride (NaCl)
- b. Distilled water (H₂O)
- c. Acetic Acid
- d. pH solution
- e. Chlorine solution

3.1.2 Equipment

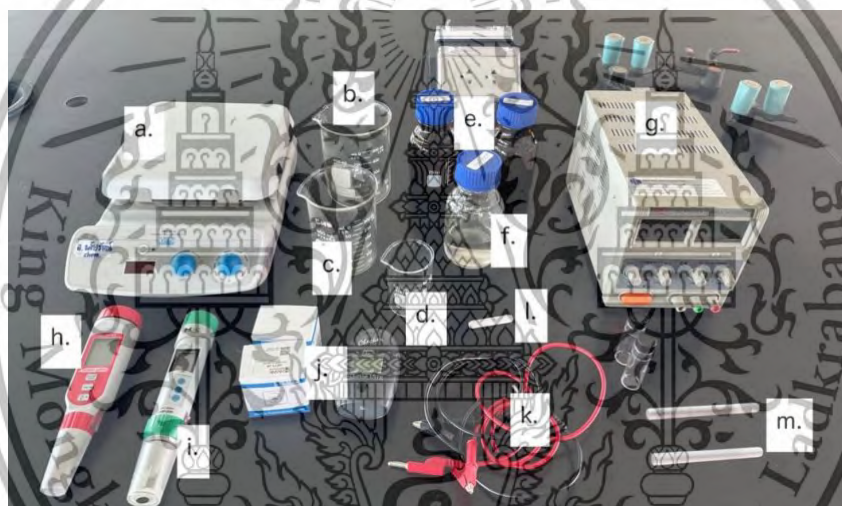


Figure 3: Equipment that used in the experiments

- a. Magnetic stirrer
- b. Beaker 600 ml
- c. Beaker 400 ml
- d. Beaker 100 ml
- e. Amber bottle
- f. Clear bottle
- g. DC power supply
- h. pH meter
- i. ORP meter
- j. Chlorine meter

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- k. Electric wire clips
- l. Stirring rod
- m. electrodes

3.2 Experiment methods

3.2.1 Generation of the electrolyzed water

- a. Weigh Sodium Chloride according to the concentration that desire.
- b. Prepare the distilled water 600 ml in a beaker.
- c. Add the weighted solution in the beaker that contained distilled water.
- d. Prepare magnetic stirrer and magnetic stirrer bar for stirring the solution.
- e. For the 2nd experiment, added the measured acetic acid into the solution.
- f. Place the beaker that contained solution on the magnetic stirrer and put the magnetic stirrer bar into the beaker.
- g. Turn on the magnetic stirrer to mix all the solution.
- h. After the solution become a homogenous solution, place the electrode into the beaker and clipped it with electric wire clip.
- i. Turn on the DC power supply to supply the electrical power to the electrode.
- j. Using the stopwatch to record the time.
- k. After the stopwatch stopped, turn off the DC power supply and take out the electrode.

3.2.2 pH measuring

- a. Turn the pH meter on.
- b. Select three pH buffer solutions that range between the expected sample pH and the buffer's pH. The first buffer should be set to 7.00, second buffer is 4.00, and the last buffer is 10.00.
- c. Pour the necessary amount of the buffer solutions into individual beakers.
- d. Place the pH meter into the pH 7.00 buffer solution. When the reading is stable, set the pH meter to the pH 7.00 value.
- e. Remove the pH meter and rinse it with distilled water. Wait until it dry.

- f. Place the pH meter into the pH 4.00 buffer solution. When the reading is stable, set the pH meter to the pH 4.00 value.
- g. Remove the pH meter and rinse it with distilled water. Wait until it dry.
- h. Place the pH meter into the pH 10.00 buffer solution. When the reading is stable, set the pH meter to the pH 10.00 value.
- i. When the pH meter calibration is done, rinse the pH meter with distilled water. Wait until it dry.
- j. Place the pH meter into the electrolyzed water sample. The pH value will be read after the number in the pH meter is stop running.

3.2.3 Oxidation-reduction potential (ORP) measuring

- a. Remove the cap of the ORP meter.
- b. Press the “ON/OFF” button. The display will become active.
- c. Dip the meter into the electrolyzed water sample to be tested.
- d. Lightly swirl the meter to ensure the removal of trapped air bubbles.
- e. The meter will display a reading almost immediately. Keep the meter in the electrolyzed water sample until the number stop.
- f. When the reading of the ORP meter is done, press the “ON/OFF” button to turn the meter off.

3.2.4 Chlorine concentration measuring

- a. Press the button to start the chlorine concentration meter.
- b. Pour 10 ml of unreacted sample into the cuvette, and replace the cuvette into the meter and close the cap.
- c. Press the button. When the display shows “Add” with “Press” blinking, it means the meter is zeroed.
- d. Remove the cuvette from the meter and unscrew the cap.
- e. Add the chlorine concentration measuring solution’s contents to the electrolyzed water sample.
- f. Replace the cap and gently shake for 20 seconds.
- g. Place the cuvette back into the meter.
- h. Press and wait for 1 minute and the instrument display the chlorine concentration in parts per million (ppm).

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Results and discussion

4.1.1 Electrolyzed water production by electrolysis

Table 1 is the result of the electrolyzed water production by electrolysis. It can be seen that adding acetic acid into the solution caused chlorine concentration and pH to decrease but caused oxidation-reduction potential (ORP) to increase. From the calculation in Section 2.5.3, adding 1.55 ml of acetic acid into 600 ml solution should reduce its pH from 8.02 to 6.5 that because acetic acid is an acidic compound, and when added into the solution, it increases the concentration of the hydrogen ions (H^+). This increase hydrogen ions contributes to a decrease in pH, making the solution more acidic. When acetic acid is added, it acts as a reducing agent by donating electrons to other species in the solution. This increase in reducing capacity leads to a rise in the ORP value. Therefore, the addition of acetic acid can cause the pH in the solution decrease and can cause the ORP of the solution to increase.

Table 1: Result for the electrolyzed water production by electrolysis

Volume (ml)	Concentration of NaCl	Volt	Time (mins)	Acetic acid (ml)	Chlorine concentration (ppm)	pH	ORP (mV)
600	4.0%	2.17	15	0	50	8.02	690
600	4.0%	2.17	15	1.5	37	6.47	838

Table 2: Ideal solution criteria

	Value of the ideal solution
pH	5.0-6.5
Oxidation-reduction potential (mV)	>800
Chlorine concentration (ppm)	10-30

Table 2 is the list of the ideal solution criteria. If the solution can be measured and received the value in between the criteria, it can be used as the antiseptic. Comparing with the Table 1, we observe that the pH value of the 1st experiment is more than the criteria for the ideal solution, and

we need to control the pH value which should be between 5.0 – 6.5. The oxidation reduction potential (ORP) would be the primary factor affecting the microbial activity. The NaCl and voltage are the important factors in determining the ORP of the electrolyzed water. From the research, a higher ORP kills more microorganisms. The ORP value from the 1st experiment is only 690 mV while the ORP value of ideal solution is more than 800 mV. The chlorine concentration play an important role than pH and ORP. In the chlorine concentration that containing 10-30 ppm was effective as a disinfectant. When the chlorine content is increase, bactericidal activity is higher. The chlorine concentration of the 1st experiment is higher than the criterial. Therefore, we need to decrease the value of the chlorine concentration to be between 10-30 ppm. As all of the value do not meet the criteria, we need to find the solution to resolve these problems.

The 2nd experiment is done to decrease the pH value of the electrolyzed. The acetic acid is the solution that we added into the electrolyzed water. As we calculated the amount of the acetic acid that we will use to decrease the pH value from 8.02 to 6.5, we need to add 1.55 ml of acetic acid in the electrolyzed water. As the result the pH value is decreased lower to be around 5.85. As we added the acetic acid into the electrolyzed water, the oxidation-reduction potential value is also increased to be 838 mV which met the criteria for the ideal electrolyzed water. The chlorine concentration from the 2nd experiment is still higher than the ideal solution criteria. However, the choline concentration may be decrease from the storage that we also experiment.

4.1.2 Electrode material

There are two types of the electrodes used to produce electrolyzed water which are the titanium electrode and the graphite electrode. The color of ideal solution of electrolyzed water is colorless. Therefore, we observed the color of the electrolyzed water by comparing the result of electrolyzed water that produced by using different electrodes. Figure 4 is the electrolyzed water that was produced by using the graphite electrode. The electrolyzed water that produced by using the graphite electrode is colorless and did not contain sediment at the bottom of the beaker. On the other hand, Figure 5 is the electrolyzed water that produced by using the titanium electrode. The electrolyzed water that produced by using titanium electrode is yellowish and contained the sediment at the bottom of the beaker that may because the titanium electrode may undergo degradation due to the electrochemical reactions occurring during the electrolysis process. This degradation can result in the release of particles or ions into the solution, leading to the formation

of sediments. The specific parameters used during the electrolysis, such as voltage and time can influence the formation of the sediments and the color of the electrolyzed water.



Figure 4: Electrolyzed water produced by using graphite electrode

Figure 5: Electrolyzed water produced by using titanium electrode

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4.1.3 Storages of Electrolyzed water

Table 3: Storage of electrolyzed water production by electrolysis

Day	pH			ORP (mV)			Chlorine concentration (ppm)		
	C, L	A, L	A, D	C, L	A, L	A, D	C, L	A, L	A, D
0	6.47	6.47	6.47	838	838	838	37	37	37
1	6.29	6.25	6.11	810	779	798	14	12	9
2	6.59	6.52	6.55	801	760	789	10	14	9
3	6.82	6.92	6.81	772	727	754	8	9	4
4	6.91	7.01	6.86	751	711	738	8	5	3
5	6.98	7.08	6.94	717	684	713	7	6	6
8	7.01	7.14	7.07	420	558	626	6	4	2
11	7.03	7.19	7.11	219	178	221	4	2	0
14	7.13	7.23	7.18	170	120	162	2	1	0

** C, L: Clear bottle in light
 A, L: Amber bottle in light
 A, D: Amber bottle in dark

Another study that we observed is the storage. We divided the storage into 3 types. The first type was that the solution is stored in the clear bottle under light circumstance. The second type was that the solution is stored in the amber glass bottle under light circumstance. The last type that was observed was the solution that is stored in the amber glass bottle under dark circumstance. Table 3 is the result of the pH value, oxidation-reduction potential and chlorine concentration that we measure from the solution that storage in different circumstance.

a. pH

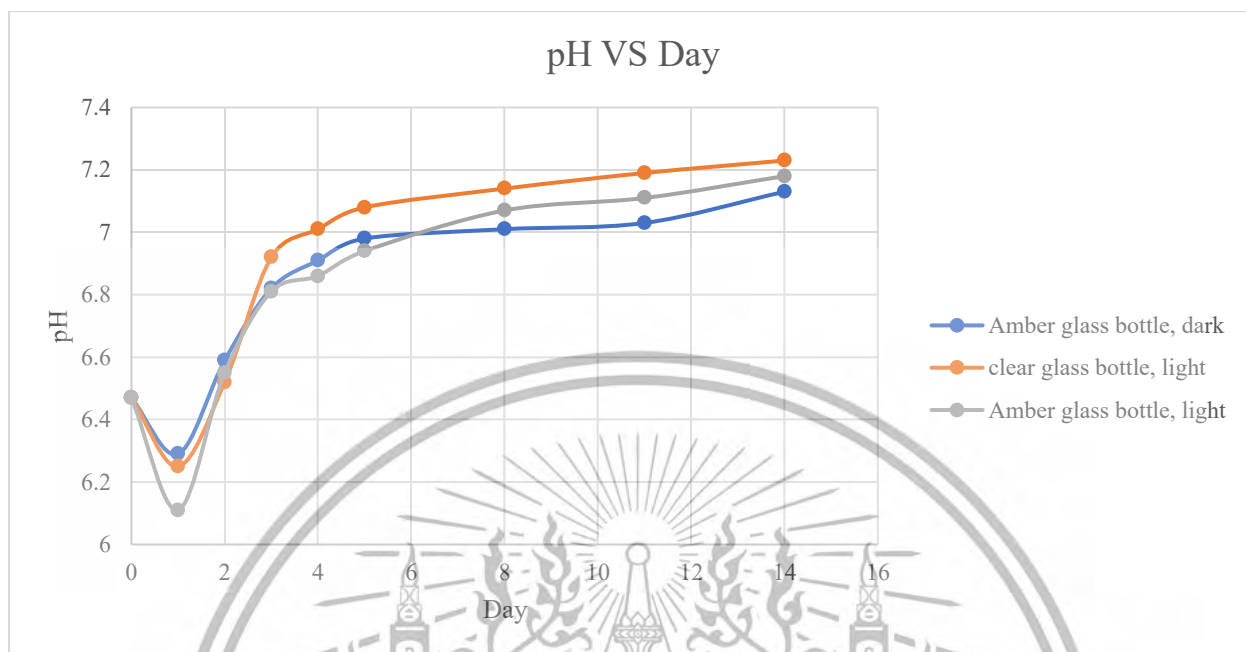


Figure 6: pH VS Day

From the research paper, the pH value of the solution will decrease in the initial after that it will increase. As shown in the Figure 6, pH VS Day, the pH values of all types are also decrease at first and after that it increased as the time increased. The most increasing pH value was the solution in the clear glass bottle under light circumstance. On the other hand, the less increasing pH value was the solution in the amber glass bottle under the dark circumstance. Therefore, the storage that is the best for the pH value of the electrolyzed water is the amber glass bottle under the dark circumstance. Because the pH value is the closest to the pH value of the ideal solution as mentioned in the Table 2.

b. Oxidation-reduction potential (ORP)

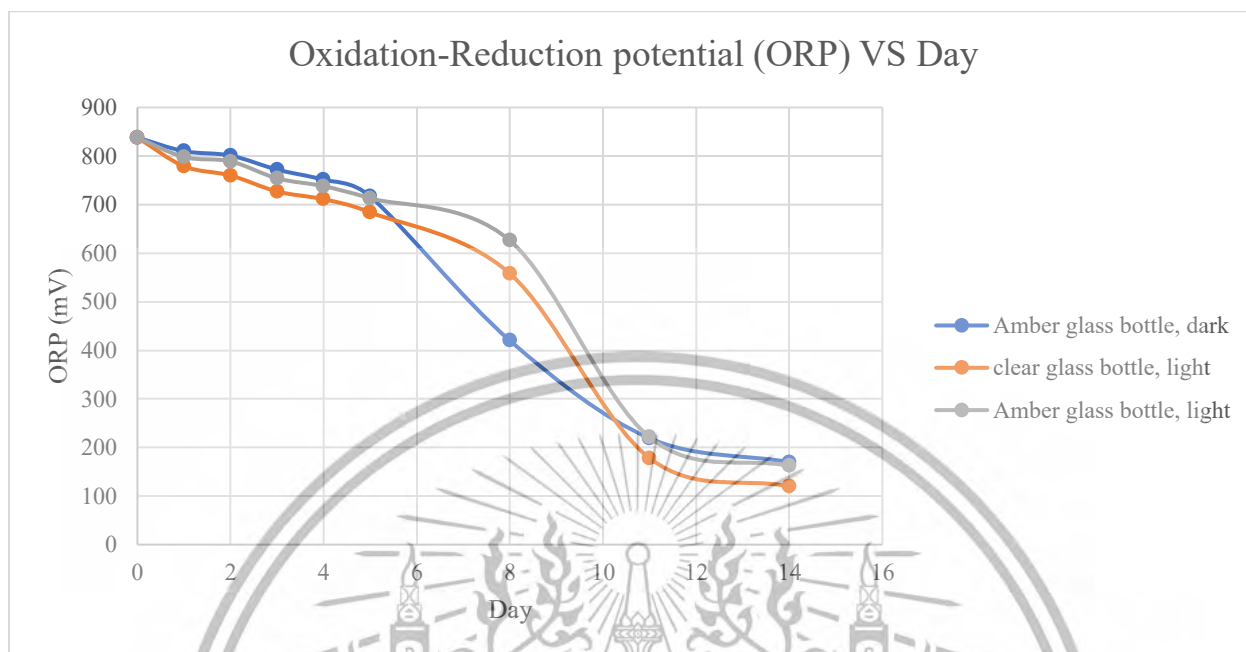


Figure 7: Oxidation-Reduction potential (ORP) VS Day

Moving on to the oxidation-reduction potential or ORP that shown in Figure 7, ORP VS Day, they all decreased as the time past. For the bottles that are stored under the light circumstance, they decreased similar to each other while the bottle that stored under the dark circumstance rapidly decreased in day 8. The dramatically decrease of the oxidation-reduction potential value was the solution in the amber glass bottle under the dark circumstance. But on the last day, the oxidation-reduction potential of the amber glass bottle under dark circumstance was the highest value among 3 types of the storage of electrolyzed water. However, all of the oxidation-reduction potential value were very less than the criteria for the ideal solution. Therefore, it needs to be further study about the stability of the value.

c. Chlorine concentration

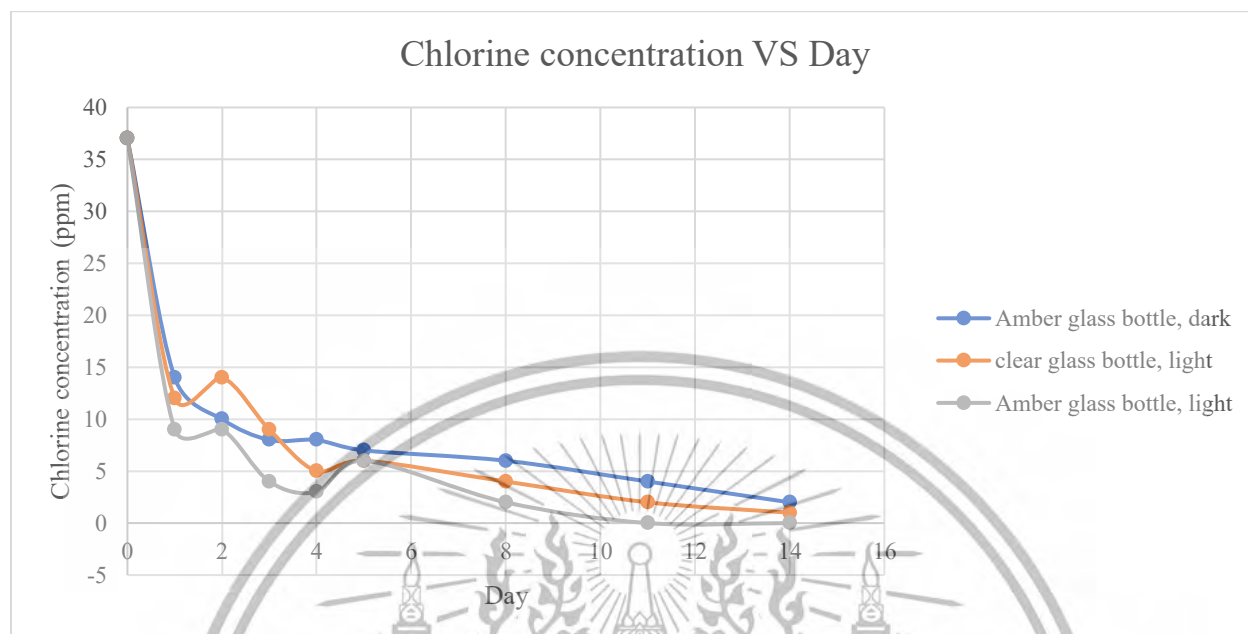


Figure 8: Chlorine concentration VS Day

The last value that we observed is the chlorine concentration, as shown in Figure 8, Chlorine concentration VS Day, all of the values in each type decreased. The dramatically decrease of the chlorine concentration was the solution that stored in the amber glass bottle under the light circumstance. For solution that stored in the clear bottle under the light circumstance, the chlorine concentration values in day 11 and day 14 are zero which means that the electrolyzed water did not contain chlorine anymore. At day 14, the chlorine concentration in the electrolyzed water that stored in the amber glass bottle under the dark circumstance was the most value among those three types which is 2 ppm.

In conclusion, the solution that store in the amber bottle under the dark circumstance shown the best storage type for the electrolyzed water with 7.13 pH value, 170 mV of ORP and 2 ppm of chlorine concentration. But it still did not meet the criterial of the ideal electrolyzed water that can be used as the antiseptic.

CHAPTER 5

CONCLUSION

The electrolyzed water is another choice for disinfectant beside alcohol-based antiseptic. The electrolyzed water is easier in terms of generation, as it can be done in a small laboratory. This can be generated by mixing sodium chlorine, with distilled water and applying the electricity by using the power DC supply to apply the electrons to the electrodes that are put in the mixture. This report proposes a method to generate the electrolyzed water and study the effect of the factors.

In this experiment, we changed the electrode material from titanium to graphite electrode, and we observed that when we changed the electrode, the color also changed. When we used the titanium electrode, the color turned yellow. On the other hand, we decided to change the electrode to the graphite electrode, the color is colorless. From the first experiment, we did not use the pH control chemical, so the pH of electrolyzed water that we produced was high. We decided to use the acetic acid to control the pH of the electrolyzed water. Acetic acid can act as a buffer, helping to maintain a stable pH in the hypochlorous acid solution. Another study that we interested in is the storage condition of the hypochlorous acid solution after we produced in the range that we want. We stored in 3 types which are in the amber glass bottle under dark circumstance, amber glass bottle with light circumstance, and the clear glass bottle with the light circumstance. This study can summarize that the recommended condition that should store the electrolyzed water is the amber glass bottle under the dark circumstance because amber glass bottle provide protection against light exposure, which can degrade hypochlorous acid over time and dark circumstance further minimize light exposure, ensuring better stability and preserving the effectiveness of the solution.

From all of the experiments that we have done in this project, it was found that there should be further study and experiments on the topics of the storage conditions of the hypochlorous acid and the stability of the electrolyzed water to make it more stable and more efficiency in its microbial activity. For the stability of the electrolyzed water, we should be further study to conduct extensive research on the impact of added carbon dioxide on the stability and properties of electrolyzed water. In conclusion, further research on the effects of added carbon dioxide in electrolyzed water solutions is highly recommended.

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Appendix A: Experimental result

Appendix A-1: Experimental result of electrolyzed water production

Table A-1-1: Experimental result of electrolyzed water production by graphite electrode

No.	Volume (ml)	Concentration	Voltage (V)	Time (min)	pH	ORP (mV)	Chlorine (ppm)	Note
1	900	0.10%	2.17	12	5.75	293	6	Graphite
2	900	0.50%	2.17	12	6	349	10	Graphite
3	900	0.90%	2.17	12	6	298	3	Graphite
4	900	0.90%	2.17	12	5.75	568	6	Graphite
5	900	1.50%	2.17	12	6	596	5	Graphite
6	900	0.70%	2.17	12	7.68	624	16	Graphite
7	900	1.20%	2.17	12	7.23	674	24	Graphite
8	900	1.50%	2.17	12	6.82	618	12	Graphite
9	900	1.30%	2.17	12	6.47	138	4	Graphite
10	900	1.20%	2.17	25	6.96	420	3	Graphite
11	500	0.70%	2.17	10	7.44	470	7	Graphite
12	500	0.90%	2.17	10	7.29	521	16	Graphite
13	500	1.50%	2.17	10	7.46	564	16	Graphite
14	500	3.00%	2.17	10	7.54	610	21	Graphite
15	500	3.00%	2.17	15	7.48	685	20	Graphite
16	500	4.00%	2.17	15	7.56	716	31	Graphite
17	500	4.00%	2.17	15	5.88	845	14	Graphite, Acetic acid
18	600	5.00%	2.17	15	7.27	658	22	Graphite, Acetic acid

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19	600	5.00%	2.17	15	6.85	700	7	Graphite, Acetic acid
20	600	4.00%	2.17	15	8.02	690	50	Graphite
21	600	4.00%	2.17	15	6.47	838	37	Graphite, Acetic acid




Table A-1-2: Experimental result of electrolyzed water production by titanium electrode

No.	Volume (ml)	Concentration	Voltage (V)	Time (min)	pH	ORP (mV)	Chlorine (ppm)	Note
1	900	0.90%	2.17	10	7.47	160	32	Titanium
2	900	0.90%	2.17	10	6.08	-142	2	Titanium, Acetic acid
3	900	2.00%	2.17	10	7.86	-308	46	Titanium
4	900	2.00%	2.17	10	5.44	-175	9	Titanium, Acetic acid
5	900	0.10%	2.17	3	8.16	-295	28	Titanium
6	900	0.10%	2.17	3	5.77	-194	4	Titanium Acetic acid

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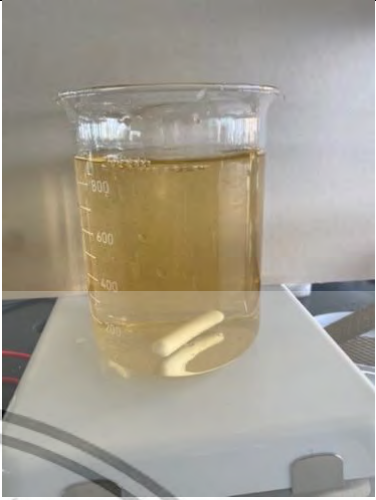


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Table A-1-3: Electrolyzed water production by electrolysis

Condition	Figure
<p>-Electrolyzed water, 0.9% NaCl</p> <p>Operating time: 10 minutes</p> <p>-Titanium electrode</p>	
<p>-Electrolyzed water, 0.90% NaCl</p> <p>-Operating time: 10 minutes</p> <p>-Titanium electrode</p> <p>-Acetic Acid</p>	
<p>-Electrolyzed water, 2.00% NaCl</p> <p>-Operating time: 10 minutes</p> <p>-Titanium electrode</p>	

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<ul style="list-style-type: none">-Electrolyzed water, 2.00% NaCl-Operating time: 10 minutes-Titanium electrode-Acetic acid	
<ul style="list-style-type: none">-Electrolyzed water, 0.10%-Operating time: 3 minutes-Titanium electrode-Acetic acid	
<ul style="list-style-type: none">-Electrolyzed water, 0.90%-Operating time: 12 minutes-Graphite electrode	

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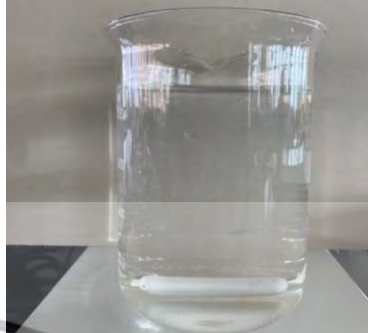
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-Electrolyzed water, 4.00% NaCl

-Operating time: 15 minutes

-Graphite electrode

-Acetic acid



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