



UNIVERSITI PUTRA MALAYSIA

***REVAMP OF EXISTING LABORATORY SCALE ELECTROLYTIC CELL
FOR ELECTROLYZED WATER STUDY IN CLEANING APPLICATION***

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ABSTRACT

The aim of this study was to revamp the existing laboratory scale electrolyzing unit in order to increase chlorine generation and current flow as well as to produce and evaluate the characteristics of electrolyzed water at optimal condition as cleaning medium in food industry. The purpose of this study is also to compare the effectiveness of revamp in chlorine generation and current flow from previous work (Sulaiman,2018). Over the last few decades, electrolyzed water has achieved immense popularity as a novel broad-spectrum sanitizer. The simplicity of production and application is the main reason for its popularity. A sustainable and green concept of electrolyzed water has several advantages over the traditional method as it can minimize the cleaning cost, on-the-spot production and safe for humans as well as the environment. The results shown that after revamp of electrolyzing unit, the chlorine generation and current flow increase significantly from previous work (Sulaiman,2018). Acidic electrolyzed water (AcEW) act as a sanitizer and it has the potential of eliminating foodborne pathogens for its high bactericidal effect. While alkaline electrolyzed water (AIEW) acts as a degreaser and can replace the use of alkaline wash. Effect of electrolyzing parameters (electrode types, NaCl concentrations, Electric voltage and electrolysis time) on the chemical and physical properties (pH, oxidation-reduction potential (ORP) and free chlorine) of electrolyzed water (alkaline and acidic electrolyzed water) were optimized by using Response Surface Methodology (RSM). From the RSM and Box Behnken Design (BBD), an optimal condition for AcEW is obtained at 0.92wt% NaCl concentration, electrolysis time of 7.79min and voltage of 15.00V to produce 2.77 pH, 1035.99 mV, 11.22mg/l free chlorine. AIEW is obtained at 0.25wt% NaCl concentration, electrolysis time of 10.00 min and voltage of 13.46V to produce 11.27pH, -424.80mV, 0.01mg/l free chlorine.

ABSTRAK

Tujuan kajian ini adalah untuk mengubah semula unit elektrolisis sedia ada untuk meningkatkan penghasilan klorin dan aliran arus dan juga untuk menilai ciri-ciri air elektrolisis pada keadaan optimum untuk digunakan sebagai medium pembersihan dalam industri makanan. Tujuan kajian ini juga untuk bandingkan keberkesanan pengubahsuaian dalam peningkatan penghasilan klorin dan aliran arus daripada kerja sebelumnya (Sulaiman, 2018). Sejak beberapa dekad yang lalu, air elektrolisis telah meraih populariti sebagai sanitizer berspektrum luas. Popularitinya adalah disebabkan kemudahan untuk dikeluarkan dan diaplikasikan. Air elektrolisis yang berkekalan dan berkonsep hijau mempunyai kelebihan berbanding kaedah tradisional kerana ia boleh mengurangkan kos pembersihan, pengeluaran segera dan selamat untuk manusia dan juga alam sekitar. Daripada keputusan eksperimen, penghasilan klorin dan aliran arus meningkat selepas pengubahsuaian semula unit elektrolisis berbanding kerja sebelumnya (Sulaiman, 2018). Air elektrolisis berasid (AcEW) mempunyai kesan bakterisida yang kuat terhadap pelbagai jenis bakteria yang ada pada makanan. Manakala, air elektrolisis alkali (AIEW) mempunyai potensi sebagai media alternatif pembersihan beralkali. Kesan parameter elektrolisis (jenis elektrod, kepekatan NaCl, arus voltan dan tempoh elektrolisis) terhadap sifat kimia dan fizikal (pH, ORP dan klorin bebas) air elektrolisis (air alkali dan asid) dioptimumkan dengan menggunakan Kaedah Surface Response Methodologi (RSM). Dari RSM dan Box Behnken Design (BBD), keadaan optimum untuk AcEW diperolehi pada 0.92 wt% NaCl, 7.79 minit tempoh elektrolisis dan 15.00V untuk menghasilkan 2.77 pH, 1035.99 mV, 11.22mg/l klorin bebas. Untuk AIEW, keadaan optimum adalah pada 0.25wt% NaCl, 10.00 minit tempoh elektrolisis dan 13.46V untuk menghasilkan 11.27pH, -424.80mV, 0.01mg/l klorin bebas.

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CHAPTER 1

INTRODUCTION

This chapter introduces on the background of electrolysis, the importance of cleaning in food industry and the implementation of electrolyzed water as a green cleaner medium in food industry. Electrolyzed water has been known as a new sanitizer for the past few years and has a lot of potential uses for the food industry. Today, food chains are becoming complicated in handling, processing, transportation, and storage ensuring a safe food supply becomes a challenge task. The use of electrolyzed water in food industry has been suggested for its high antimicrobial activity, low cost and ease production and use for cleaning purposes. Cleanliness of food processing equipment is essential to prevent food contamination and provide a safe food product for consumer.

1.1 Background of electrolysis

Electrochemistry is the study of chemical processes that cause electrons to move. This movement of electrons is called electricity, which can be generated by movements of electrons from one element to another in a reaction known as an oxidation-reduction ("redox") reaction. A redox reaction is a reaction that involves a change in oxidation state of one or more elements.

The word "electrolysis" was first introduced by a man named Michael Faraday in the 19th century, and was suggested by Rev. William Whewell. Electrolysis was used as a tool to study the chemical reactions to obtain a pure element. Table below shows how electrolysis had helped numerous scientists for their research purposes.

Table 1.0: Contribution of electrolysis in research (Encyclopædia Britannica 3rd edition, 1797)

1785	Martinus van Marum's electrostatic generator was used to reduce tin, zinc, and antimony from their salts using electrolysis.
1800	William Nicholson and Anthony Carlisle (view also Johann Ritter), decomposed water into hydrogen and oxygen.
1808	Potassium (1807), sodium (1807), barium, calcium and magnesium were discovered by Sir Humphry Davy using electrolysis.
1821	Lithium was discovered by the English chemist William Thomas Brande, who obtained it by electrolysis of lithium oxide.
1833	Michael Faraday develops his two laws of electrolysis, and provides a mathematical explanation of his laws.
1875	Paul Émile Lecoq de Boisbaudran discovered gallium using electrolysis
1886	Fluorine was discovered by Henri Moissan using electrolysis.

1886	Hall-Héroult process developed for making aluminium
1890	Castner-Kellner process developed for making sodium hydroxide

Electrolysis is a process by which electric current is passed through a substance to effect a chemical change. Oxidation and reduction reactions occur when electrons are transferred and this is called chemical change. Molecules that is oxidized loses an electron and molecules that is reduced gains the electron that was lost by the oxidized molecule.

The main components required to achieve electrolysis are electrolyte, direct current (DC) and 2 electrodes. Electrolytes are a solution composed of free ions which carry electric current in the electrolyte. The ions must be mobile and cannot be solid salts or the electrolysis process will not work. The electrodes provide the physical interface between the electrolyte and the electric circuit that provides the energy.

Electric current enters through the negatively charged electrode (cathode) and the positively charged atoms of the solution travel to this electrode, combine with the electrons, and are transformed to either neutral elements or molecules. The negatively charged components of the solution travel to the other electrode (anode), give up their electrons, and are transformed into neutral elements or molecules. Over time, the electrode will eradicatd and dissolve by giving up electrons.

Throughout the years electrolysis have been applied into many fields including electroplating, electrometallurgy and waste water treatment. Electroplating is a process that uses an electric current to reduce dissolved metal cations so that they form a thin layer of metal coating in an electrode. Electroplating is primarily used to change the surface properties such as abrasion, wear resistance and corrosion of any specific object. Besides that, electroplating also can be used to build up thickness on undersized parts or to form objects by electroforming. For example, silver chloride is used to make a coating for silver wire using silver electrodes by electroplating process.

Electrometallurgy involves metallurgical processes that take place in an electrolytic cell. Electrowinning and electro-refining are the most common types of electrometallurgy. Electrowinning is an electrolysis process used to recover metals in aqueous solution, usually as the result of an ore having undergone one or more hydrometallurgical processes. The metal of interest is plated onto the cathode, while the anode is an inert electrical conductor. Electro-refining is used to dissolve an impure metallic anode to produce a high purity cathode (Boundless, 2015).

The continuous need for energy and food with the increase growing world population is forcing the exploration of the wastewater recycling and resource recovery. Since water is very limited, it is important to not waste it after having been used in the industrial process. Today, the biological treatments are not enough as they have a few disadvantages such as they take a very long time and require a large area for treatment. Electrolytic wastewater treatment is rarely used in compare to chemical treatment. Nevertheless, this treatment is more effective to produce high quality water (Chopra, Kumar Sharma, & Kumar, 2011).

1.2 Electrolyzed water as a green cleaner in food industry

Cleanliness and hygiene in food production is a high stakes consideration. Nowadays everyone depends more or less on packaged foods from newborns to senior citizens. Therefore, food manufacturer should provide consumers with safe food products. The majority of food industries are using chemical cleaning agent on food contact surfaces of all equipment involved at all step of productions. The usual chemical used for cleaning are organic acids, chlorine compound and iodophores.

Green cleaning can be defined as using cleaning methods and medium with environmentally friendly ingredients and procedures which are designed to preserve human health and environmental quality. The main concern of green cleaning is to avoid using medium which contain toxic chemicals which can harm to not only the user but also the environment. The purpose of green cleaning is also to reduce waste. For some homes, using substances such as baking soda, vinegars and lemons to clean home surfaces is also considered to be green cleaning. Some households prefer using manufactured green cleaning products, however this can only be considered as green cleaner if and only if they do not contain harmful chemicals such as phosphates, artificial fragrances, and artificial colors.

The application of electrolyzed water has been used in various food industry and also in hospitals. Guentzel and others (2008) has reported the effectiveness of electrolyzed water treatment on spinach and lettuce while Yarahmadi and others (2012) reported that the most suitable alternative to chlorine for the treatment of leafy greens is AEW. The exposure time of fresh vegetables and fruits to AEW plays a key role in reducing the microbial count.

For the poultry and meat industry, electrolyzed water is being used for cleaning as the microbial contamination in pork and meat is a critical factor to meat quality. To reduce microbial contamination in meat and poultry, numerous intervention technologies including chlorine and EW treatment have been applied (Ding and others 2010; Rahman and others 2012, 2013). This is because EW has been reported to be effective against populations of bacteria that are associated with chicken, pork and meat surface such as *Listeria monocytogenes*, *Escherichia coli*, *Salmonella typhimurium*, and *Clostridium jejuni*.

Not only that, since the development of foodborne prevention outbreaks, EW has already shown promising results as a sanitizer for seafood and fish. The sushi industry in Japan has saved millions of dollars by washing raw fish with EW. Bacterial cross-contamination can occur from the preparation equipment and tableware during food processing. Therefore, it is important to have a proper cleaning and sanitization of the tools used in the food industry. In this context, EW has been the major sanitizers to reduce bacterial count to a certain level.

However, the major difference of using electrolyzed water compared to cleaning chemicals is the price. Excluding the machine necessary to produce electrolyzed water, the use of electrolyzed water combined with the shortened run time allow for a 30 to 40 percent cheaper cleaning process (Mclaurin, 2016).

The market for electrolyzed water as sanitizer is currently small. This is due to the installment of electrolysis machines is expensive and food manufacturers are not aware of the benefits of using electrolyzed water for a safer less harsh way of keeping factories free from infectious pathogens.

1.3 Cleaning in food industry

Cleaning in food industry is not an easy task. However it is a critical step within food production since it the most important step to maintain and guarantee food safety. Understanding why we can clean and how detergents and disinfectants work is the key to ensure a safe and hygienic manufacturing environment. Most food manufacturers take cleaning very lightly. This will effect the environment of the workplace and also effect the quality of the product.

Levels of cleaning that have to be considered is physically clean, chemically clean and microbiologically clean. Physically clean addresses the aesthetic aspect. The surface appears clean, but chemical residues, often deliberately left to achieve a particular desired effect, may have been allowed to remain and disinfection of the surface has not been considered. The chemically clean surface is rendered totally free from any trace of chemical residues and microbiologically clean addresses the degree of microbiological contamination (Tamime, 2008).

During cleaning, cleaning solutions used include various type of detergents, sanitizers and disinfectants. The commonly used alkali detergents are Sodium Hydroxide, Potassium Hydroxide, sodium Carbonate etc and the acid detergents include Hydrochloric Acid, Nitric Acid, Phosphoric Acid and Citric acid. Disinfectants used in the food processing industry include oxidizing agents such as hypochlorite, hydrogen peroxide, ozone and per acetic acid. Denaturing agents like alcohol based products and non-oxidizing and surface tension diminishing agents and enzyme based products are also used (Troller, 1993).

It is important to specify the correct processing times of cleaning methods, as long standing cleaning process will cause fouling on the surface of processing equipment especially in heat exchanger plate, which result in growth of harmful thermophilic bacteria (Wirtanen and Salo, 2003).

1.3.1 The process of cleaning

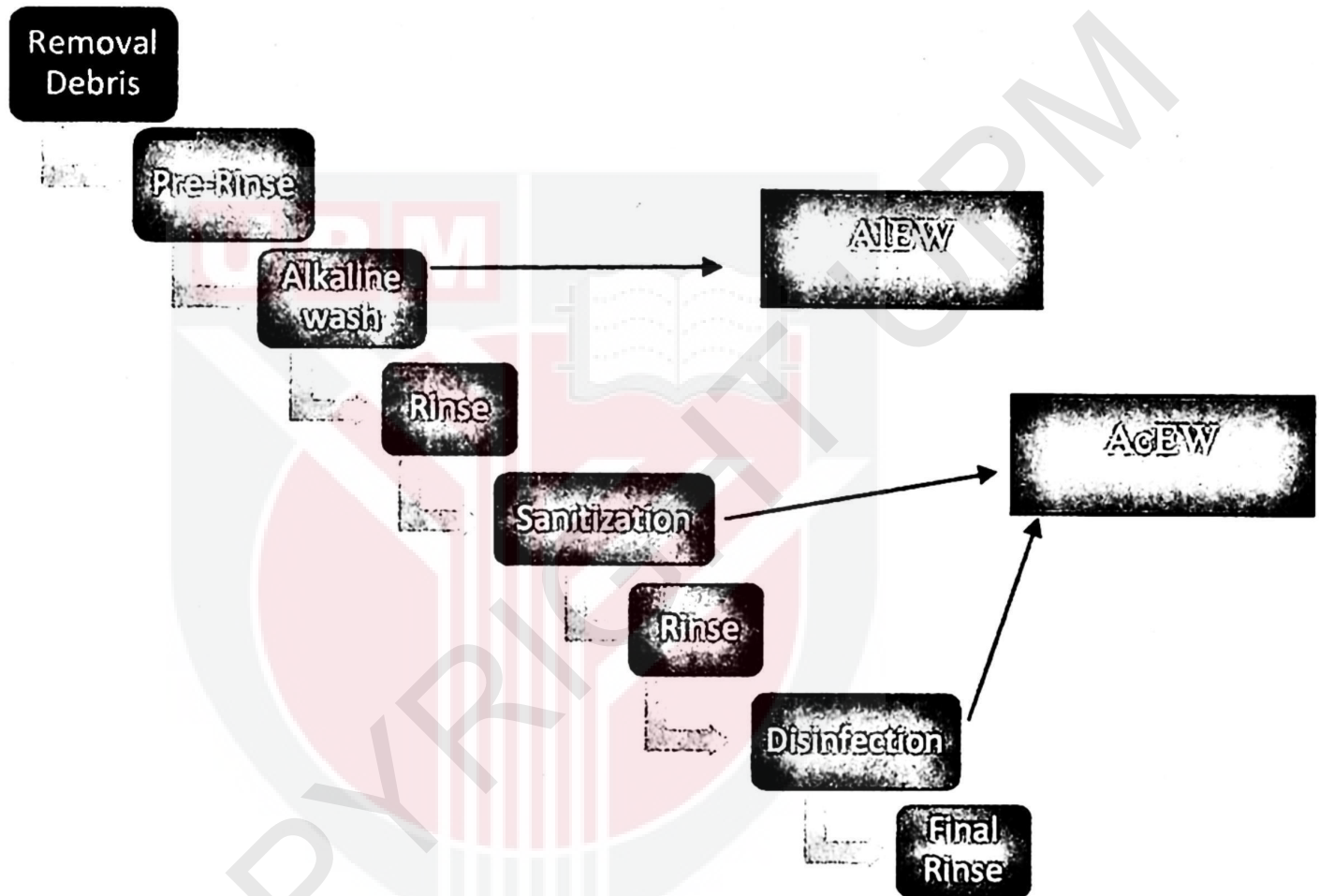


Figure 1.0: 8 steps cleaning process (Tamime, 2008)

The cleaning process tends to follow a similar principle such as manual or automated and throughout all industry sectors. The discrete stages or cycles will usually consist of a general series which is stated in Figure 1.0. However, the use of electrolyzed water can replace alkaline wash, sanitization and disinfection and replace it with AIEW and AceW accordingly. This will not only minimize the cleaning cost but also saves time for acidic wash as it skips 2 cleaning process and combine it into one. AIEW can be replace with alkaline wash as it contains sodium hydroxide while AceW can replace both sanitization and disinfection process as it contains sodium hypochlorite.

1.4 Problem Statement

Previously, the amount of chlorine and current flow generated by the electrolyzing unit is far less than the theoretical value. For AcEW, a high concentration of chlorine is needed as it has a bactericidal effect making it an efficient cleaner or disinfectant. A high ORP value is required as for cleaning because the higher the ORP, the more the oxidation occur thus killing the bacteria by stealing the electrons in their DNA, cell membrane and protein. A high pH value is also required as certain microbes could not survive in extremely low or high pH value. Therefore, it is essential to produce a low pH value, high ORP and a high free chlorine in electrolyzed water. This can be accomplish through the modification of the existing electrolyzing unit.

Chemical pollution presents a host of dangers to both humans and wildlife. Toxic chemical spills can cause immediate, short-term devastation to the environment and anyone exposed to the substances. However, much more insidious is the long-term effects of chemical pollution, which can harm those far away from the initial source of contamination and over a much longer period.

Green cleaning is using products and procedures that are safe for the environment and do not emit any pollutants when used. Green cleaning is important not only for the environment and our planet, but for the health of the general public. Green cleaning products are made to not pollute and to be better for the environment. However, it remains important to check each product to find the best quality, least harmful product.

Consumers have become more demanding in regard to healthy and safe food putting pressure on food producing and handling companies. Contaminated food and water often cause by bacteria, viruses, parasites and chemical substances are the main cause of foodborne illnesses. Thus, an effective cleaning system is required to preserve a cleaner and healthier environment for food production. The use of harmful chemicals in equipment and machines may lead to potential hazard if not handle with proper procedure.

Food manufacturers also has to take into consideration a low cleaning cost but an effective cleaning, meaning the quality of the food product have to be preserved while figuring out ways to stabilize their income and profit (Huang, Hung, Hsu, Huang, & Hwang, 2008).

The reason why electrolyzed water is not widely used in our industry is mainly because not many local food manufacturers are aware of the existence of such product. Also, it is a norm to our society that detergent has to be soapy and have a nice smell in order for something to be clean. However, if one do have the knowledge of cleaning using electrolyzed water, the cost of purchasing an electrolyzing unit is expensive to them and would just use cheap cleaners instead.

Basically, the main reason of this study is to not use chemical cleaner as it will cause damage to both the equipment and also the user if it is not handled properly. Preparing electrolyzed water will produce 2 types of detergents at the same time that can be readily used. Thus, it can be used as an alkaline wash and also as a sanitizer at the same time of production. It also made up of only salt and distilled water so it does not require a high cost to produce compared to buying commercialized cleaners. The low concentration of chlorine will not corrode the equipment easily. Also, if there is residue, after a period of time it will convert back to it's normal state which is just salt water. Therefore, it will not cause food contamination or harm the environment if it was to go down the drain.

1.5 Objectives of the study

This project is a continuation work from Sulaiman (2018) and it is actually a small part of an on-going PhD work. The objectives of this project are:

- i. To revamp existing lab-scale electrolyzing unit to increase current flow and chlorine content in electrolyzed water
- ii. To optimize electrolyzing parameters (NaCl concentration (0.1-1.0wt %), Voltage (5, 10&15 V), electrolysis time (10, 20, 30 minutes) on chemical and physical properties (pH, oxidation-reduction potential (ORP), total residue chlorine, dissolve oxygen, electrical conductivity) of **acidic and alkaline electrolyzed water.**
- iii. To investigate the effect of revamp on electrolyzed water properties.

CHAPTER 2

LITERATURE REVIEW

In this chapter, it reviews the previous studies and their findings related to the area of application of electrolyzed water in cleaning systems which involves the roles of electrolyzed water as sanitation liquid or medium and as antimicrobial agent. This chapter also explains the effects of electrolyzing parameter on physical and chemical properties and effects of physical and chemical properties on cleaning effectiveness.

2.1 Electrolyzed water as cleaner

According to (Huang et al., 2008) electrolyzed water was initially developed in Japan as it has been reported to have a strong bactericidal effect on most pathogenic bacteria that are important to food safety. In recent years, electrolyzed water gained its popularity in agriculture, dentistry medicine and food industry as it has been shown to be an effective sanitizer for cutting boards, poultry carcasses, food processing equipment and more (Huang et al., 2008). Today, the

effectiveness of using electrolyzed water as a sanitizer is still being studied in countries such as Japan, China and USA (Aq, Ugiyama, & Sobe, 2005).

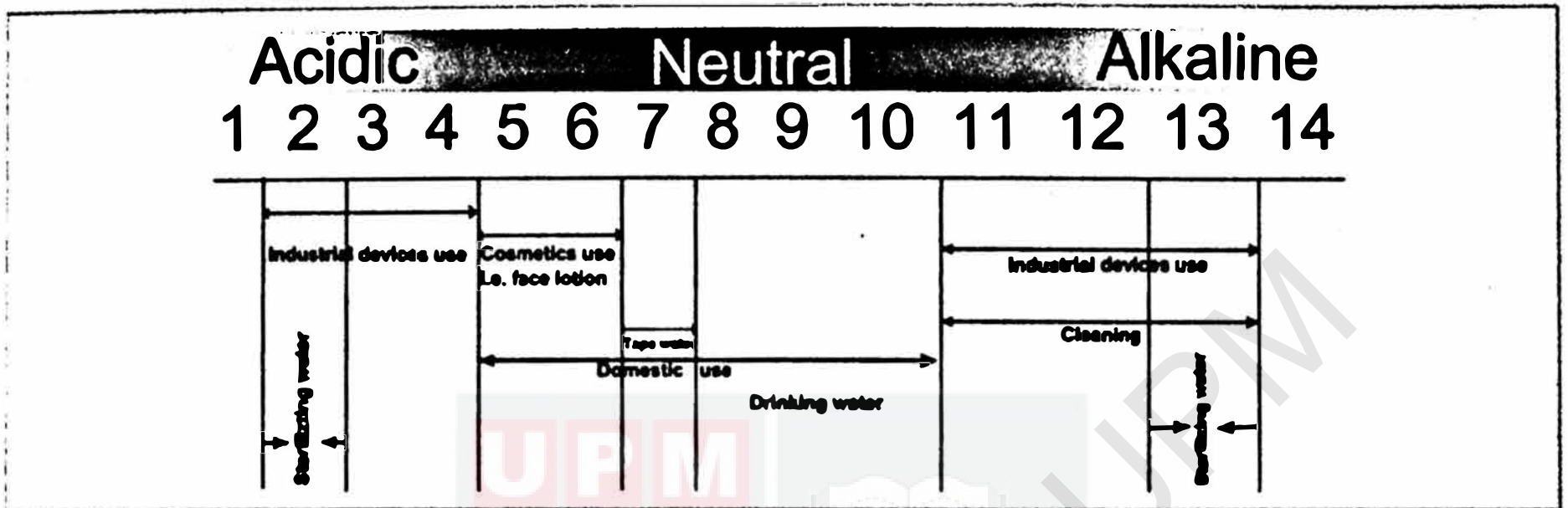


Figure 2.1: Applications of electrolyzed water at different values of pH in various field
(Rahman, Khan, & Oh, 2016)

As shown from the figure, for acidic electrolyzed water (AEW), the pH ranges between less than 1 to 3 is best use for industrial dives and cosmetic use. On the other hand, for alkaline electrolyzed water, the pH ranges between more than 10 to 13 is also best for industrial devices and also for cleaning purposes.

According to (Zeng et al., 2010) Traditional disinfectants cannot meet today's demand because of its distinct smell, low stability and also toxic debris. Electrolyzed water has the potential to be more compelling, less harmful and less costly compared to most traditional preservation method.

2.2 Electrochemistry of Electrolyzed Water

The making of electrolyzed water will produce two types of electrolyzed water are generated which are acidic electrolyzed water (AEW) at the anode and basic electrolyzed water (BEW) at the cathode (Rahman et al., 2016).

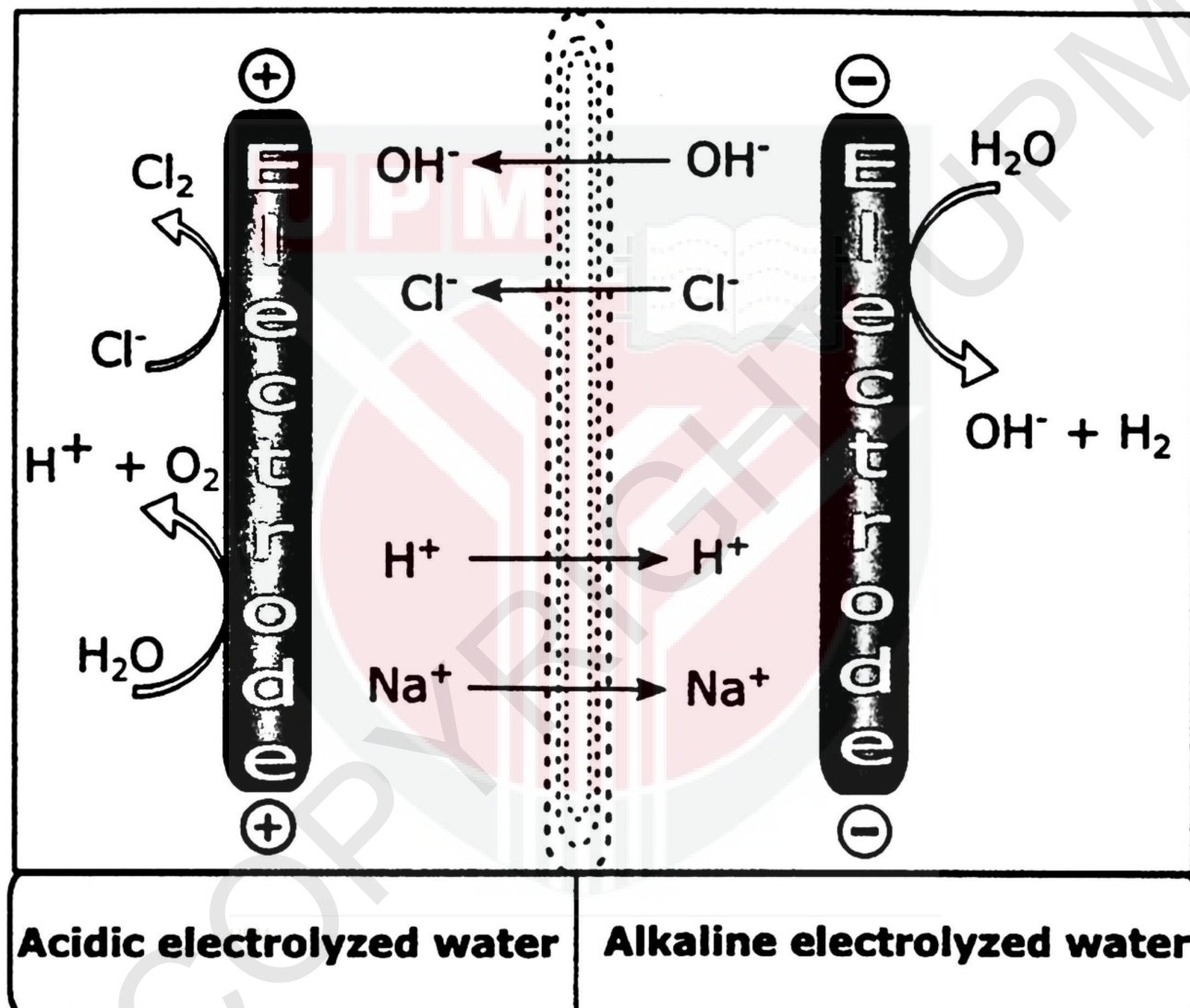
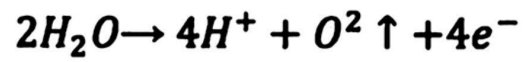


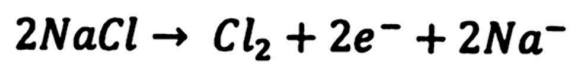
Figure 2.2: Generation of AEW and ALEW in an electrolytic cell (Rahman et al., 2016)

According to the figure above, the basic chemical reaction at anode chamber are as follows:

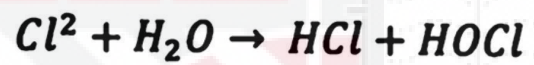
Equation 2.2.1



Equation 2.2.2



Equation 2.2.3

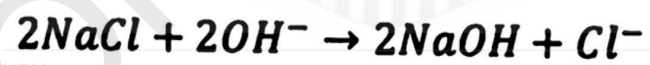


While the chemical reaction at the cathode reaction are:

Equation 2.2.4



Equation 2.2.5



2.3 Effect of electrolyzing parameter on physical and chemical properties of electrolyzed water.

According to (Rahman et al., 2016) the sanitization effect of electrolyzed water has various factor that has been thought to be responsible for the affect of physicochemical properties which are current, electrolyte, salt solution electrode materials, storage conditions and water temperature. Also, the antimicrobial efficacy of electrolyzed water is highly influenced by the value of ORP, concentration of (Cl_2 , OCL and HOCl) and pH (Len et al., 2000). The optimal choice for electrode gap and cell potential depends on the chlorine level of the electrolyzed water while the optimal choice for electrolysis time depends on the electrolyzable chlorine in electrolyzed water and cell potential in adopted for electrolysis.

2.3.1 Relationship between current and salt concentration in Electrolyzed water

The effectiveness of electrolyzed water can increase and decrease by the amperage of the generator as it influences the concentration of chlorine (Park et al 2001). According to (Rahman et al., 2012) the impact of current flow on the sanitizing effectiveness of electrolyzed water by increasing it from 1.15A to 1.45A, a log reduction of 4.9-5.6 CFU/mL for both *E.Coli* and *L.monocytogenes* was achieved. Apart from that, the values of ORP and pH increased with the increase of current value. Hsu (2005) proved that higher salt concentration leads to high salt concentration and conductivity of electrolyzed water. During electrolysis process, there is a linear correlation between the amount of NaCl used and the amount of HOCl being produced (Al-Haq et al., 2002,2005).

2.3.2 Relationship between electric potential and electrolysis time in chlorine generation

According to (G. W. Hsu, Lu, & Hsu, 2016) the electric potential is one of the key factor of the key factor of high chlorine generation. This is because the electric current will increase as the cell potential increase, thus increasing the current density. Based on the results, it stated that as electrolysis time increase chlorine concentration also increase at low electric potential. While chlorine concentration decreases with high voltage and short electrolysis time. The results also shown that voltage at 7.5 V and electrolysis time at 342 minutes, they were able to generate 10,498 mg Cl₂/L.

2.3.3 Relationship between electrode gap and electric current on chlorine generation

According to (G. W. Hsu & Hsu, 2017) the electrode gap does not bring any significant effect on the chlorine generation. However, with the increase of current density and electric current, the chlorine concentration also increases. The electric potential increase significantly with the decreasing distance between electrode which is the electrode gap. However, in the study, the reason electrode gap did not bring any significant effect to the chlorine generation is due to constant current mode was chosen for their study. During electrolysis process, electrode gap and electric current affected current efficiency. Smaller electrode gap and low electric current appears to be more energy efficient for the electrolysis system.

2.3.4 Types of electrodes

Jeong et al (2009) stated that choice of electrode material plays a major role in the productions of oxidants. Not only that, they also said that the material used as the anode influence the generation of reactive oxygen species which are OH, O₃ and H₂O₂. Sanitization potential of electrolyzed water is greatly influenced by the type of electrodes materials chose where the order of electrode materials are arranged as follows: Ti/IrO₂ > Ti/RuO₂ > Ti/Pt-IrO₂ > BDD > Pt (Rahman et al., 2016). According to Hsu et al (2015) production of chlorine is at bare minimum if titanium is paired as cathode and anode as titanium have low electrical conductivity. On the other hand, stainless steel has a higher electrical conductivity and have lesser chance to corrode. This is because of the presence of oxide layer due to the addition of chromium.

2.3.5 Electrode potential in the galvanic series upon corrosion of electrode

Makhlouf, A. S. H. (2015) stated that a galvanic corrosion is an electrochemical action of two different metals in the presence of an electrolyte and a conductive electron path. When two different metals are connected, a potential difference usually exist. Therefore, the corrosion for the more resistant metal is produced as the corrosion of less resistant metal is increased. In other words, the further apart the metals in the galvanic series the less the corrosion. Palit, S (2018) stated that in a galvanic couple, a more resistant metal (noble metal) has to be placed at the cathode as it corrodes much slower, while a more active metal act as the anode since it corrodes faster. Other factor that affects galvanic corrosion are size of the anode, types of metal and operating conditions (Humidity, temperature, salinity etc).

Choosing metals with that share the same electrode potential can also minimize corrosion. This is because the smaller or the closer matched the individual potentials, the smaller the potential difference therefore the galvanic current will be smaller.

Metal	Steady-state potential, negative to a saturated calomel half-cell (volts)
18/8 stainless steel (passive)	0.08
Hastelloy C	0.08
Monel	0.08
Titanium	0.10
Silver	0.13
Inconel	0.17
Nickel	0.20
70/30 cupronickel	0.25
80/20 cupronickel	0.27
90/10 cupronickel	0.28
Admiralty brass	0.29
Gunmetal	0.31
85/15 gilding metal	0.33
Copper	0.36
63/37 brass	0.36
Naval brass	0.40
18/8 stainless steel (active)	0.53
Carbon steel	0.61
Cast iron	0.61
Aluminum	0.79
Zinc	1.03

Figure 2.3: The Galvanic series based on potential measurement in flowing seawater at 25° C

(Ahmad, Z. 2016)

2.4 On target Cleanliness

2.4.1 Physically

Theoretically, physically clean can be defined as the surface appears to be clean to the eye. However, there may be chemical residue been allowed to remain. Disinfection of the surface has not been considered. According to (Rahman et al., 2016) the U.S. Food and Drug Administration (FDA 2009) reported a serious problem on improper cleaning and sanitization of the tools used in the food industry. Therefore, to ensure food safety, a proper cleaning and sanitizing process of these equipment and tools should be optimize. In this context, a novel sanitizing agent which is AEW has been employed to reduce the bacterial count on food contact surfaces and this has been examined by several researchers (Izumi 1999; Deza and others 2005; Deza and others 2007).

2.4.1 Chemically

Chemically clean can be defined as the surface is free from any chemical residues. Electrolyzed water is made up only of table salt (NaCl) and distilled water therefore it is made in an environmentally friendly fashion water (Hri-cova et al 2008). Commercialized cleaners that is usually use in food industry to clean equipment have the tendency to cause chemical contamination and will harm consumers. This will likely to occur if the equipment still have chemical residue after final rinse. Interestingly, over time electrolyzed water will tum into its normal form thus it will not harm humans and the environment (Al-Haq et al 2005). Electrolyzed water is also proven to be less corrosive compared to commercialized cleaners. Apart from that, its shelf life is reduced along with time thus its acidity and alkalinity is also reduced.

2.5 Response Surface Methodology (RSM) as a tool for Optimization.

Optimization can be define as a method to improve the performance of a system, a process or a product to achieve the maximum benefit of it. It is very commonly used in analytical chemistry which is to apply a procedure that produces the most appropriate response. Optimization of analytical procedure needs precision, therefore it must be carried out by using a multivariate statistic technique. The most reliable multiverse technique used in analytical is response surface methodology (RSM).

Response surface methodology is a collection of mathematical and statistical techniques based on the fit of a polynomial equation to the experimental data, which must describe the behavior of a data set with the objective of making statistical previsions. It is suitable to use when a set of responses have different variables. To simultaneously optimize the levels of the variables is the main objective as it will attain the best system (Talanta, 2008).

2.6 Summary

In food industry, electrolyzed water is used as an antimicrobial agent that have strong antimicrobial activity towards bacteria and pathogens that are important for food safety. Electrolyzed water is also implemented in the food industry for it's green cleaning capability. Different electrolyzing parameters (NaCl, concentration, voltage, electrolysis time and electrode material) are studied. This chapter reviews some of the studies conducted by several previous researchers related to electrolyzed water production. This chapter provide a better understanding and an insight for a better electrolyzed water production.

CHAPTER 3

METHODOLOGY

For this study, the optimization of electrolyzed water is performed by manipulating electrolyzing parameters (type of electrodes, NaCl concentration, electrolysis time and voltage) that will affect the physical and chemical properties (pH, ORP, free chlorine and total chlorine) on acidic and alkali electrolyzed water. The experiment was conducted by manipulating parameters, which are NaCl concentration (0.05-1.0wt%), voltage (5-15V), electrolysis time (5, 7.5, 15 minutes) and types of electrodes (Stainless Steel and Titanium).

3.1 Revamp work

This revamp work is done to get a more significant result compare to previous study by (Sulaiman, 2018). The revamp work is focusing mainly on how to increase the chlorine generation better than before. A few weaknesses were first identified that could have caused a small amount of chlorine being generated. One of them are, the electrode plate was not placed at the right position, low current flow and the usage of metal screws in the electrolysis chamber.

The electrode plates are responsible for the ionic exchange and the reason to produce a better acidic and alkaline electrolyzed water. Therefore, it is essential for them to be positioned in a correct position for a better ionic exchange between them. Previously, the electrodes were not in a fix position. They were not facing each other and the distance between them is quite far apart. A 10-slot stopper was added to the walls of both chambers to hold the electrodes in place whilst facing each other. The purpose for the electrodes to face each is other is to improve ionic exchange between them. Not only that, the slot manage to create an electrode gap between the 2 plates, which is 1cm apart from each other. (G. W. Hsu & Hsu, 2017) stated that a small electrode gap, which is less than 11.7 mm, and operating at a low electric current appear to be more energy efficient.

Makhlouf (2015) stated that a galvanic corrosion is an electrochemical action of two different metals in the presence of an electrolyte and a conductive electron path. When two different metals are connected, a potential difference usually exist. Therefore, the corrosion for the more resistant metal is produced as the corrosion of less resistant metal is increased. In other words, the further apart the metals in the galvanic series the less the corrosion. According to table 2.0 from the Galvanic series, the electrode potential of Titanium and Stainless are 0.08V and 0.10V respectively. Since both of the metals are relatively close to each other it will

minimize corrosion, therefore Stainless steel and Titanium are chosen as electrode for this work. Since stainless steel is more noble than Titanium, therefore Stainless Steel was chosen for the anode while Stainless steel and Titanium was chosen for the cathode. This is to minimize corrosion from occurring in the electrolytic chamber that could disrupt the electrolysis process. Another way to minimize corrosion is to minimize the use of metal in the electrolysis chamber. Previously, the membrane separating both AcEW and AlEW were held by a membrane holder which was held by a metal screw. The membrane holder was then removed and replaced with a slot-like holder similar to the one that holds the electrode plate. Not only that it minimizes the use of metal but also makes the removal and insertion of membrane much easier.

Last but not least, to increase current flow we removed the alligator clips and replaced it with a copper wire that connects it directly from the power supply to the electrode plates. By doing this, we can minimize the resistance from the power supply therefore increasing the current flow. A new power supply is then used to replace the existing power supply. The new power supply has a setting which we can control the amount of current that is desired. However, the current flow will depend on the experimental set-up itself but we manage to increase it to a significant amount.

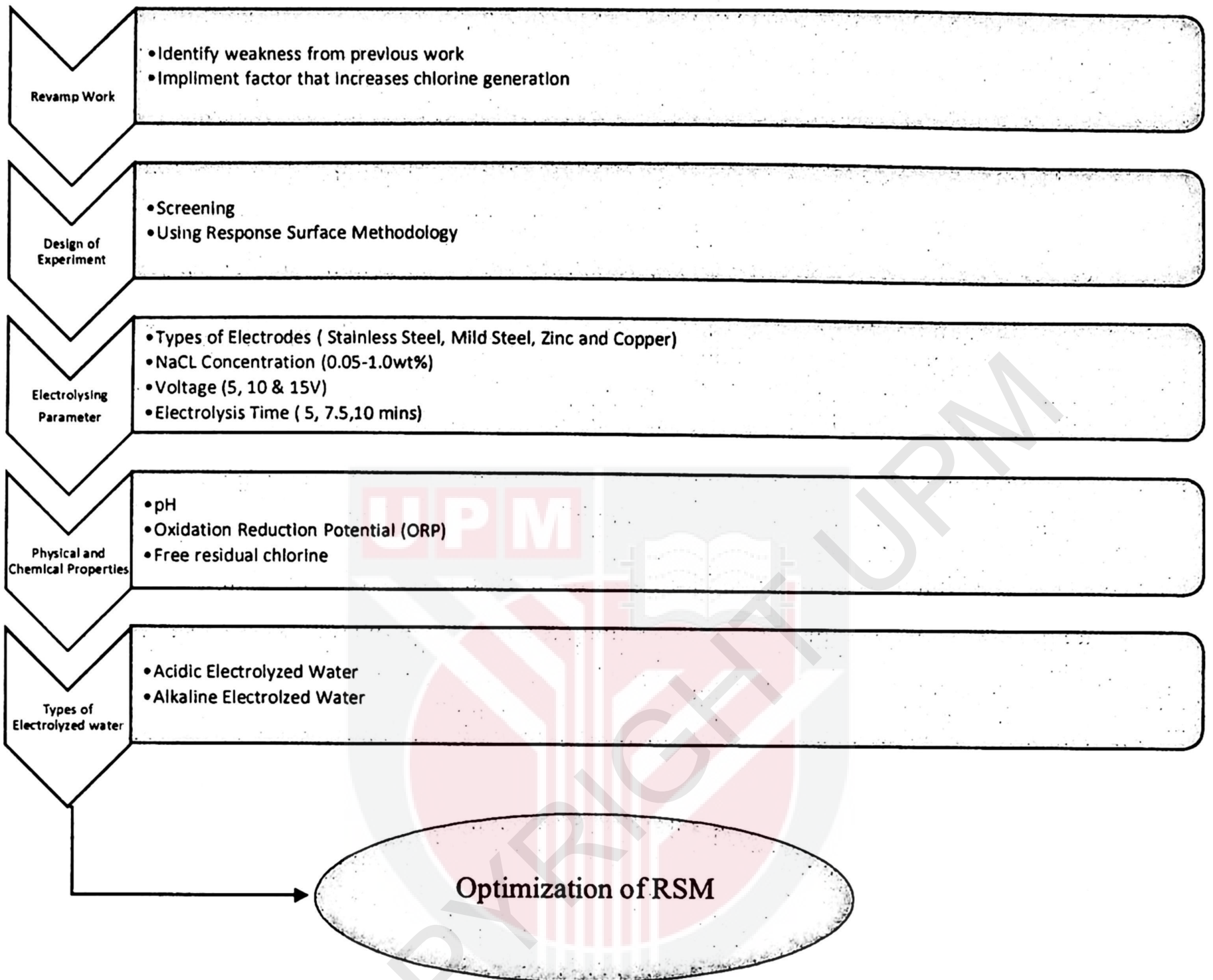


Figure 3.0: Flow chart summary of the whole experiment

3.2 Experimental Set-up

The production of electrolyzed water is first by preparing the salt solution. There are 3 types of concentration used (0.05, 0.53 and 1.0 wt.%). The concentration of salt solution is determined by ratio of distilled water used. Then, the salt solution is poured into the ionizer and to start the electrolysis process the DC power supply is connected. In this electrolysis process, AcEW and AlEW is produced in 2 chamber set-up which anode and cathode is separated by membrane that allow ion exchange. AcEW and AlEW are collected at anode and cathode respectively. In this work, Stainless Steel is used as anode and different electrode type (Stainless Steel and Titanium) are used as cathode.

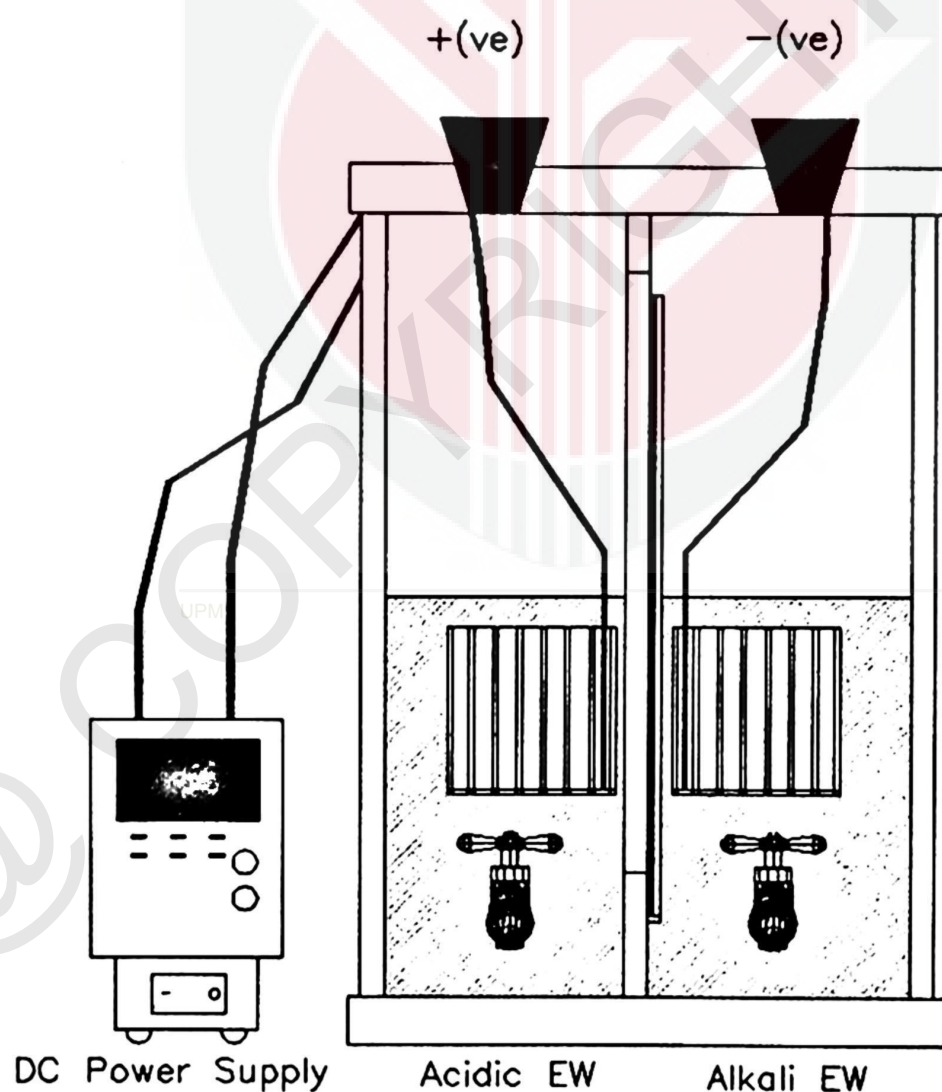


Figure 3.1: Schematic diagram of the lab-scale electrolyzing unit

3.3 Materials and Chemicals

3.3.1 Electrode types

The selection of electrode is based on its properties of electrical conductivity, corrosiveness and current efficiency.

Different electrode types is used to study the efficiency on the physical and chemical properties of the electrolyzed water. Stainless Steel (10 x 10cm) is set as anode and Stainless Steel (10 x 10cm) and Titanium(10 x 10cm) from Good Fellow Cambridge Limited, Huntingdon, England. The electrodes is set alternately at cathode to see the different effectiveness on electrolyzed water produced.

3.3.2 Chemical type and concentrations

For the preparation of electrolyzed water, salt solution is prepared by using Sodium Chloride (NaCl) Grade AR, from Friedman Schmidt Chemical. Below is the equation to determine the concentration of NaCl where x indicate the weight of NaCl.

$$\frac{x}{3400(ml)} \times 100\% = \%of NaCl \quad \text{(Equation 3.0)}$$

3.3.3 Solvent type

In order to get the uniformity of solvents, distilled water is used as the solvents to dissolve the salt, sodium chloride (NaCl) to three different concentration (0.05, 0.53 and 1.0wt%).

34. Lab scale electrolyzing unit



Figure 3.2: Lab-Scale electrolyzing unit

From the figure above, the electrolyzed water is produced using a Lab-scale electrolyzing unit. A lab scale electrolyzing unit is used because it can manipulate many parameters than the commercialized machine for electrolyzed water. The fabricated electrolyzing unit can manipulate voltage, electrolyte concentration, time for electrolysis and types of electrodes.

3.4.1 Determination of pH



Figure 3.3: AP85 Portable Waterproof pH/conductivity meter

For this experiment, the initial pH is taken at both chamber anode and cathode after the solution of salt is done as a control point. After the electrolysis is done, the value of pH of both side is taken by using pH probe and record the data. For pH is measure with pH/mV/ISE meter with pH electrode from the Fisher Scientific, USA.

3.4.2 Determination of Oxidation-Reduction Potential (ORP)



Figure 3.4: PT-380 Hand-held pH/ORP/Temperature Meter

For this study, a higher oxidation reduction potential value is required. The reading of oxidation potential is taken at both sides before the electrolysis process to indicate as the set point. Then, the reading is taken after the electrolysis process is done and the value was recorded for every test of experiments. It measures in millivolts using pH/mV/ISE meter equipped with redox electrode from Boeco, Germany.

3.4.3 Determination of Total and Free residual chlorine



Figure 3.5: Photometer PF-3 Macherey Nagel

For this experiment, the value of chlorine is taken before the electrolysis process start. After the electrolysis process is done, the value for both free and total chlorine is recorded. Then the sample is added with 1 spoon of Cl_2 -1 in powder form and shake for 20 seconds. After that, the solution is let rest for 1 minutes for the reaction time. Then, the closed tube is placed in the chlorine meter and the reading was taken and recorded for every experiment.

For the total chlorine test, a 5ml sample is taken into closed test tube and added with 1 spoon of Cl_2 -1 in powder form. Then the sample is shake for 20 seconds to blend the mixture completely. The solution is let to rest for 3 minutes and placed into the chlorine meter to take and record the reading for each experiments. It is measured using Photometer from Macherey-Nagel Germany.

3.4.4 Determination of Dissolved Oxygen (DO)



Figure 3.6: HI 9147 Dissolved Oxygen Meter

For this study, the value of dissolved oxygen is taken before the electrolysis process. After the electrolyzed water is produced, the sample at both alkali and acid solution is taken and insert with dissolved oxygen meter. The reading of dissolved oxygen is recorded for every test. It is measure using an oxygen meter from Hanna Instruments, USA.

3.5 Response Surface Methodology (RSM)

Response surface methodology (RSM) is an experimental design method for experimental process optimization. It is based on statistical and mathematical experiment design method. The objective of using RSM is to simultaneously optimize the levels of these manipulating factors to gain the best performance of electrolyzed water. RSM is to optimize the electrolyzing parameter to yield the peak performance of electrolyzed water in cleaning application. It is to evaluate the interaction and relationship on effect of variables and obtained response surfaces to obtain an optimum condition.

Table 3.0: Box-Behnken design experiment factors and levels

Code	Factor	Level		
		-1	0	1
X_1	NaCl Concent.	0.05wt%	0.53wt%	1.0wt%
X_2	Electrolysis time	5mins	7.5mins	10mins
X_3	Voltage	5V	10V	15V

3.6 Summary

The work for this study is divided into 2 main parts. In the first part is the production of electrolyzed water by using lab scale electrolyzing unit on different electrolyzing parameter (NaCl concentration (0.05-1.0wt%), Voltage (5, 10&15V). electrolysis time (5,7.5,10 minutes) to obtain the results for pH, ORP, free chlorine and total chlorine. In the second part, the results obtain for pH, ORP, free chlorine and total chlorine from the lab work were optimize by using Response Surface Methodology and Box-Behnken Design to obtain the optimal condition of electrolyzed water.

CHAPTER 4

RESULTS AND DISCUSSION

In this chapter, the results for revamping of existing lab scale electrolytic cell to increase chlorine generation. The method from previous study was changed completely which are the electrolysis time, voltage and NaCl concentration. From the electrolytic cell point of view, a two-factor central composite design to study the effects of electrode gaps and electrical current on chlorine efficiency was adopted. The results obtained are compared to the previous study to observe the changes in term of chlorine generation from the old electrolytic cell to the revamped electrolytic cell. Only titanium and stainless steel was compared in this study.

The results analysis and discussion on the effect of different electrolyzing parameters (NaCl concentration, electrolysis time, electrode type, and voltage) on the physio-chemical properties (pH, Oxidation-Reduction Potential and Chlorine content) of (alkaline, acidic and neutral) electrolyzed water on the new electrolytic cell are present in this chapter. Acidic electrolyzed water (AcEW) can be used as sanitizer for cleaning as it has high antimicrobial properties while alkaline electrolyzed water (AlEW) can act as a replacement for alkaline wash or degreaser. Three independent variables which are (NaCl concentration, electrolyzing time, voltage) is evaluated using Response Surface Methodology (RSM) to predict the optimized electrolyzed water to use in cleaning food contact surfaces in food industry. The results obtained from RSM were used to determine the optimized condition for electrolyzing parameter to produce electrolyzed water with high cleaning effectiveness. Validation was done using the expected result from RSM and the results is compared with the empirical data.

4.1 Revamp of Lab-scale electrolytic cell

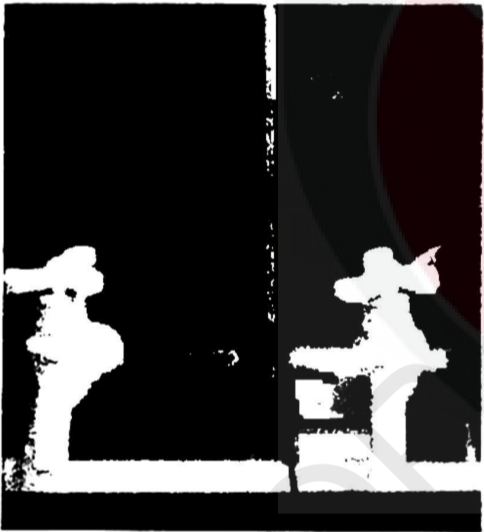

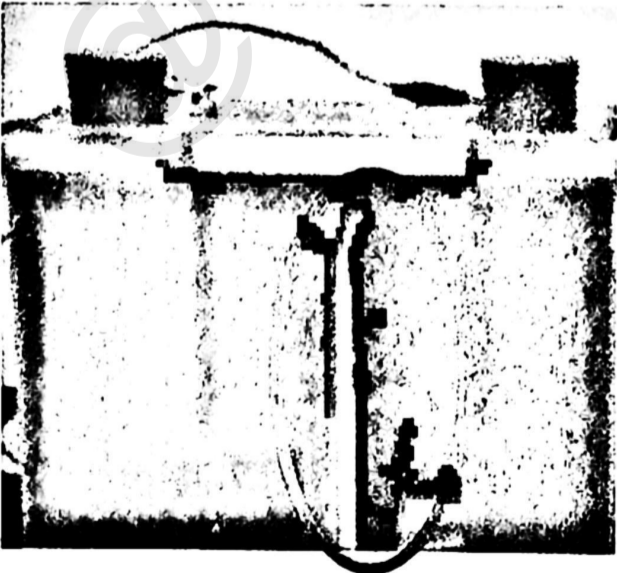

Electrolyzed water has been known as a new sanitizer and cleaner as it is produced from regular water and without the addition of any harmful chemicals, except for NaCl. Therefore, it is essential to produce the best quality and having the highest efficiency in cleaning. To achieve such results some modification has been made to the existing lab scale electrolyzing unit to increase the chlorine generation. Some of the features are there has to be an electrode gap between the electrode plate. The smaller the gap between the electrodes and the closer the electrodes, the higher the electric potential (G. W. Hsu & Hsu, 2017). Chlorine concentration depends on the amount of electric current passing through the electrodes. Therefore, a stopper was added to the walls of the electrolyzing unit to hold the electrode thus creating a gap. The stopper also has a number of gaps for the electrode to slip in. Not only that the stopper provides electrode gap, but also makes the electrodes facing towards each other. This provides a better ion exchange from the cathode to the anode.

To minimize the use of metal in the electrolyzing unit, the membrane holder was removed. This is because the membrane holder uses bolts to hold the membrane in place. The presence of foreign metal in the electrolytic cell could affect the electrolysis process, therefore it was removed. The bolts used was made up of stainless steel 304. Stainless steel 304 contains 18% chromium and 8% nickel. Compared to stainless steel 316, it contains molybdenum which helps to resist corrosion in salt water (Applications, Panels, Frames, & Standards, n.d.). Upon running a few tests before removing the membrane holder, the salt solution appears to be brown in color which indicates corrosion of the bolts. The membrane holder was removed and was replaced with a clear plastic holder. The design is the same for the slots to hold the electrode plates, which is like a socket. This does not only reduce corrosion, but also makes it easy to

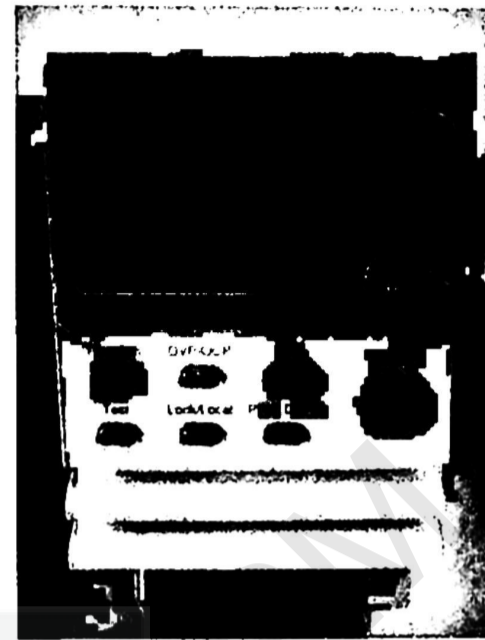
remove and insert the membrane separating both solutions. Both the membrane holder and the stopper were glued using silicon.

To increase current generation and reduce resistance, alligator clips was removed and a new power supply was used. By removing the alligator clips, current will flow directly to the electrodes hence reducing resistance. The new power supply can control the amount of current needed for the electrolysis process whilst the old one could not.

Table 4.0: Revamp work on the electrolytic cell from the previous to the present design to increase chlorine generation and current flow

Previous work (Sulaiman, 2018)	Present work
1. Addition of slot to fix the electrode position	
	
2. Removal of metal screws from the membrane holder	
	

3. Use a new power supply to increase current generation



4. Removal of alligator clips



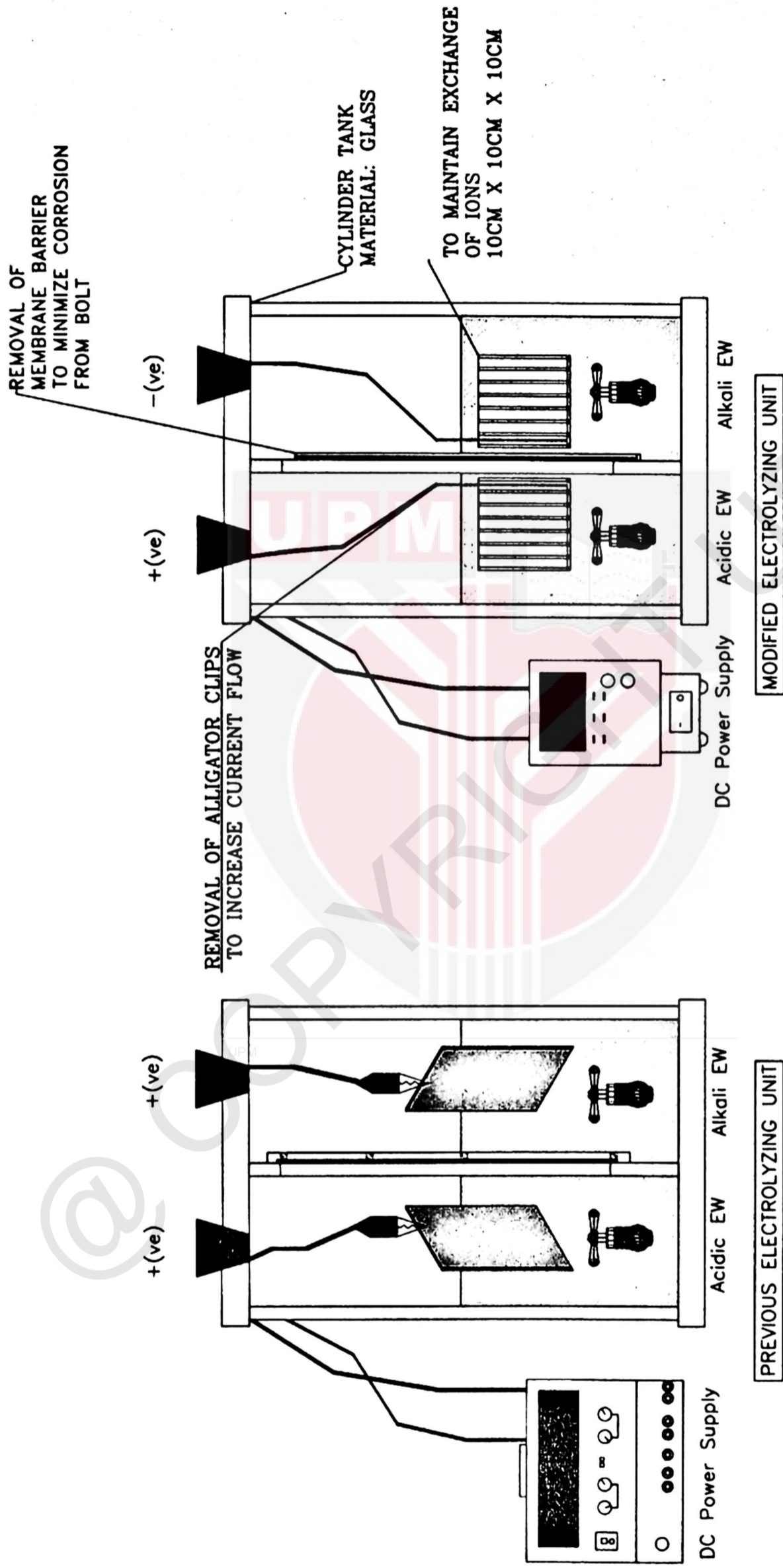


Figure 4.1: Schematic drawing of the previous electrolyzing unit and the existing electrolyzing unit

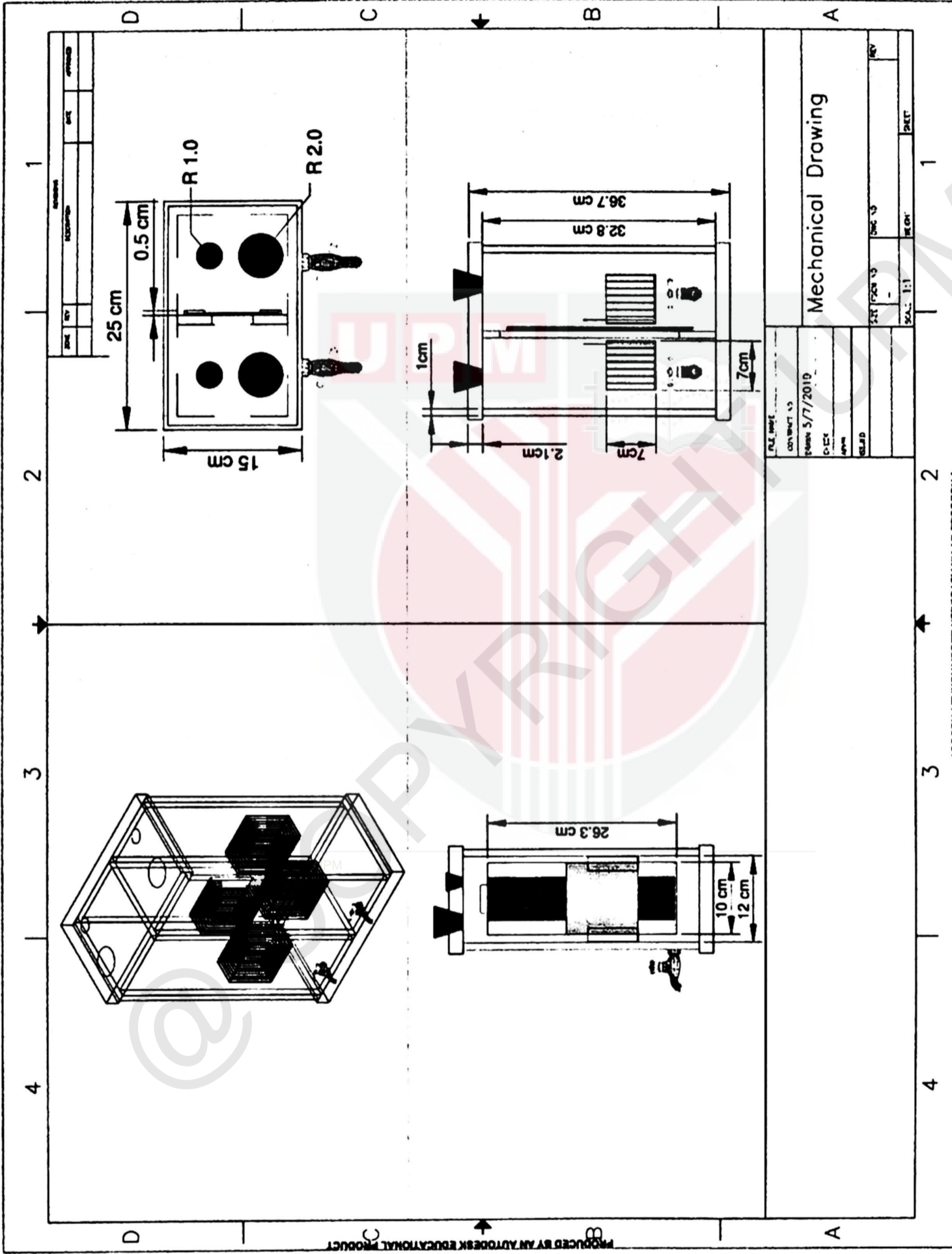


Figure 4.2: Mechanical drawing of existing lab scale electrolyzing unit

4.2 Effect of revamp on the chlorine generation and the physico-chemical properties

Small businesses are constantly updating their products with new packaging, various features and updated designs and functions. Revamp should only be executed when there is a reason to change that will bring better result as it comes with a high price. For this work, the results were compared with the results obtained by previous work by (Sulaiman, 2018) with the present work. By comparing the results obtained, we can observe the difference or changes revamp work brings. For (Sulaiman, 2018) work the factors value used is different from this work. The factors used for both work is the same which are NaCl concentration, voltage and electrolysis time. However, the values used are different. Sulaiman, (2018) used a range of NaCl concentration of 0.1wt%(4g), 0.5wt%(20g), 1.0wt%(40g), electrolysis time was (10mins, 20mins and 30mins) and the voltage used was (9V, 16V and 24V). While for this work, the range of NaCl concentration used was 0.05% (1.7g), 0.53% (18.02g), 1.00% (34g), electrolysis time was (5mins, 7.5mins and 10mins) and the voltage used was (5V, 10V and 15V). The results are to compare only the AcEW to identify whether the revamp of the electrolytic cell brings any significant effect to the chlorine generation.

The most significant result from (Sulaiman, 2018) (Table 4.1) is compared to the most significant result from this work (Table 4.2). For (Sulaiman, 2018) work, the electrodes used for the anode is Titanium while the electrode used for the cathode is Stainless Steel. However for this work the most significant results use Stainless Steel as the anode while Titanium was used as the cathode. The chemical properties for both work used are different from one another. This was both compared as different parameters brings different results for both work.

Table 4.1: Physico-chemical properties of Titanium/Stainless Steel AcEW at 10 minutes

(Previous work Sulaiman,2018)

NaCl Concentration (%)	Voltage (V)	Current (A)	pH	ORP (mV)	Free Chlorine (mg/L)	Total Chlorine (mg/L)
10 minutes						
0.5	16	0.013	4.66	372	0.23	0.26

Table 4.2: Physico-chemical properties of Stainless Steel/ Titanium AcEW at 10 minutes

NaCl Concentration (%)	Voltage (V)	Current (A)	pH	ORP (mV)	Free Chlorine (mg/L)	Total Chlorine (mg/L)
10 minutes						
0.53	15	2.50	2.77	999	4.57	4.88

(Present work)

From the results we can see that the free chlorine concentration of (Table 4.1) is much lower than the free chlorine concentration of (Table 4.1). The concentration of NaCl from the previous work is much lower than than the concentration of the present work. This may cause the low chlorine generation for the previous work because (S. Hsu, 2005) stated that as NaCl concentration increases, the chlorine generation increases significantly. As for the voltage, the settings used are almost similar however the current generation from the previous work is much lesser than the present work. This is probably due to the experimental setup of the electrolytic cell such as the use of aligator clips instead of using hooks directly to the electrodes. This will cause a higher resistance thus lowering the current flow. (G. W. Hsu et al., 2016) stated that as electrolysis time increases, chlorine generation will increase significantly. The electrolysis time used for both work is the same which is at 10 minutes. The results shown that revamp work has bring a significant effect on the chlorine generation and also the current flow.

4.3 Effects of NaCl Concentration on the physico-chemical properties

The chlorine generation increase significantly with NaCl concentration (S. Hsu, 2005). The NaCl concentration used for this work are 0.05% (1.7g), 0.53% (18.02g), 1.00% (34g) that is diluted with distilled water. Two types of electrodes (stainless steel, Titanium) are used for the electrolysis process gives different effect on pH, Oxidation-Reduction Potential (ORP), free chlorine and total chlorine. During two chamber electrolysis process, AcEW can be collected at the anode and the ALEW can be collected at cathode. In this work Stainless Steel is fixed at the anode. Table 4.1 and Table 4.2 shows results for 2 chamber electrolysis, Stainless steel as anode electrode, 7.5 minutes electrolyzing time.

For AcEW using Titanium as cathode (Table 4.1), as the concentration of NaCl increased, the pH and ORP also increased. Increasing the NaCl concentration from 0.05% to 1.00% has a positive effect as it increases chlorine concentration. A good AcEW with high antimicrobial activity has low pH, high chlorine content and high ORP. As expected, the ORP increase as the NaCl concentration increases. For concentration 1.00% (34g), it appears that the ORP value is slightly higher than the ORP value of concentration of 0.53% (18.02g). This is probably due to the ORP value will not increase more eventhough more NaCl is used. For AcEW using Stainless Steel as cathode (Table 4.3), as the concentration of NaCl increased, the pH and ORP also increases. When the NaCl concentration increased from 0.05% to 1.00% it also increases chlorine generation.

A good AIEW which has a cleaner characteristics has high pH, low ORP value (negative values). Usually AIEW does not have any chlorine content. For AIEW, both Table 4.2 and Table 4.4 shows the pH, increased when the NaCl concentration is increased. While ORP gradually decreasing as NaCl concentration increases. In this work, AIEW contains chlorine. Increasing the NaCl concentration, increase the chlorine concentration. This may be due to leaking of AcEW through the gaps between the membrane to the AIEW. Therefore from the results, the higher the chlorine generation in AcEW, the more chlorine leaks through thus also increases the chlorine content in AIEW.

Table 4.1: Effect of different electrolyzing parameters on physio-chemical of AcEW for Titanium as cathode.

NaCl Concentration (%)	pH	ORP (mV)	Free Chlorine (mg/L)	Total Chlorine (mg/L)
7.5 minutes				
0.05	4.27	487	0.28	0.33
0.53	3.32	980	6.10	7.38
1.00	2.81	982	13.81	14.30

Table 4.2: Effect of different electrolyzing parameters on physio-chemical of AIEW for Titanium as cathode.

NaCl Concentration (%)	pH	ORP (mV)	Free Chlorine (mg/L)	Total Chlorine (mg/L)
7.5 minutes				
0.05	8.39	-119	0.04	0.04
0.53	10.92	-412	0.24	0.25
1.00	11.55	-521	0.24	0.27

Table 4.3: Effect of different electrolyzing parameters on physio-chemical of AcEW for Stainless Steel as cathode.

NaCl Concentration (%)	pH	ORP (mV)	Free Chlorine (mg/L)	Total Chlorine (mg/L)
7.5 minutes				
0.05	4.00	458	0.24	0.32
0.53	3.04	956	3.96	4.16
1.00	2.94	782	1.53	1.76

Table 4.4: Effect of different electrolyzing parameters on physio-chemical of AIEW for Stainless Steel as cathode.

NaCl Concentration (%)	pH	ORP (mV)	Free Chlorine (mg/L)	Total Chlorine (mg/L)
7.5 minutes				
0.05	6.89	76	0.11	0.12
0.53	10.88	-339	0.15	0.16
1.00	11.52	-399	0.56	0.58

4.4 Effects of electrolysis time on physic-chemical properties.

The concentration of chlorine increased significantly with time (Huang et al., 2008). For this study, different electrolysis time are (5 minutes, 7.5 minutes, 10 minutes). Effect of electrolysis time is most significant on the production of chlorine in electrolyzed water where the chloride is converted to chlorine after undergo electrolysis process for a certain time interval. The trends for the production of chlorine is observed from the table results below for electrode Titanium and Stainless Steel.

Table 4.5 Free and Total Chlorine Content for AcEW Titanium, 5 and 10 minutes

NaCl Concentration (%)	Voltage (V)	Free Chlorine (mg/L)	Total Chlorine (mg/L)
5 minutes			
0.05	10	0.20	0.21
0.53	15	2.80	2.09
1.00	10	1.65	2.26
10 minutes			
0.05	10	0.13	0.15
0.53	15	4.57	4.58
1.00	10	2.08	2.21

Table 4.6 Free and Total Chlorine Content for ALEW Titanium, 5 and 10 minutes

NaCl Concentration (%)	Voltage (V)	Free Chlorine (mg/L)	Total Chlorine (mg/L)
5 minutes			
0.05	10	0.12	0.11
0.53	15	0.17	0.19
1.00	10	0.09	0.10
10 minutes			
0.05	10	0.05	0.06
0.53	15	0.19	0.22
1.00	10	0.13	0.14

Table 4.7 Free and Total Chlorine Content for AcEW Stainless Steel, 5 and 10 minutes

NaCl Concentration (%)	Voltage (V)	Free Chlorine (mg/L)	Total Chlorine (mg/L)
5 minutes			
0.05	10	0.12	0.19
0.53	15	1.96	2.30
1.00	10	0.55	0.72
10 minutes			
0.05	10	0.40	0.44
0.53	15	2.66	4.75
1.00	10	0.71	0.81

Table 4.8 Free and Total Chlorine Content for AIEW Stainless Steel, 5 and 10 minutes

NaCl Concentration (%)	Voltage (V)	Free Chlorine (mg/L)	Total Chlorine (mg/L)
5 minutes			
0.05	10	0.08	0.12
0.53	15	0.16	0.19
1.00	10	0.08	0.15
10 minutes			
0.05	10	0.11	0.14
0.53	15	0.23	0.27
1.00	10	0.16	0.18

From table 4.5 and table 4.6 for electrode Titanium at 5 and 10 minutes above, it shown that as electrolysis time increases the production of free chlorine and total chlorine also increase. From the results, for AcEW at 15V, 0.53% NaCl, when electrolysing time is increased from 5 to 10 minutes, the chlorine content (free and total chlorine) increased. For 5 minutes, the free chlorine and total chlorine are 2.80 and 2.09 mg/L respectively. While at 10 minutes, the free chlorine and total increased to 4.57 and 4.58 mg/L respectively. Therefore from the results, its by Huang et al., that electrolysis time gives time interval for the chlorine to be generated and being built in electrolyzed water. However, by increasing electrolysis time, DO (dissolve oxygen) and temperature of EW was not affected. This also implies to table 4.7 and table 4.8 for Stainless

Steel electrode. From the results, for AcEW at 15V, 0.53% NaCl, when electrolysis time is increased from 5 to 10 minutes, the chlorine content (free and total chlorine) increased. For 5 minutes, the free chlorine and total chlorine are 1.96 and 2.30 mg/L respectively. While at 10 minutes, the free chlorine and total increased to 2.66 and 4.75 mg/L respectively.

4.5 Effects of Voltage on physic-chemical properties.

(G. W. Hsu et al., 2016) stated that as the electric potential increases, the higher the amount of electric current passes through the system and the higher the current density will be. Also, chlorine concentration depends on the amount of electric current passing through the electrodes. Therefore, electric potential is the main driving force of the electrolysis system to the production of chlorine.

From the results, increasing the electric voltage, reduced the pH value and increase the ORP, free chlorine and total chlorine content for both Titanium and Stainless Steel in Table 4.9 and 4.11. While for AIEW, from Table 4.10 and 4.12 it shows that as the electrical voltage increased, the value for pH, ORP, free and total chlorine also increased.

Table 4.9: Free and Total Chlorine Content for AcEW Titanium, at 5V and 15V

NaCl Concentration (%)	pH	ORP (mV)	Voltage (V)	Free Chlorine (mg/L)	Total Chlorine (mg/L)
5 minutes					
0.53	4.39	410	5	0.29	0.33
0.53	3.68	801	15	2.80	2.09
7.5 minutes					
0.05	5.25	397	5	0.32	0.16
0.05	4.27	487	15	0.28	0.33
1.00	3.78	721	5	4.77	5.00
1.00	2.81	982	15	13.81	14.30
10 minutes					
0.53	4.25	419	5	0.31	0.39
0.53	2.77	999	15	4.57	4.88

Table 4.10: Free and Total Chlorine Content for ALEW Titanium, at 5V and 15V

NaCl Concentration (%)	pH	ORP (mV)	Voltage (V)	Free Chlorine (mg/L)	Total Chlorine (mg/L)
5 minutes					
0.53	7.49	-69	5	0.10	0.11
0.53	9.62	-92	15	0.17	0.19
7.5 minutes					
0.05	5.73	322	5	0.06	0.07
0.05	8.39	-119	15	0.04	0.04
1.00	10.64	-107	5	0.20	0.22
1.00	11.55	-521	15	0.24	0.27
10 minutes					
0.53	10.23	-57	5	0.10	0.11
0.53	11.56	-630	15	0.19	0.22

Table 4.11: Free and Total Chlorine Content for AcEW Stainless Steel, at 5V and 15V

NaCl Concentration (%)	pH	ORP (mV)	Voltage (V)	Free Chlorine (mg/L)	Total Chlorine (mg/L)
5 minutes					
0.53	4.83	308	5	0.16	0.19
0.53	3.47	496	15	1.96	2.30
7.5 minutes					
0.05	4.61	381	5	0.16	0.21
0.05	4.00	458	15	0.24	0.32
1.00	3.58	410	5	0.60	0.71
1.00	2.94	782	15	1.53	1.76
10 minutes					
0.53	4.73	311	5	0.40	0.44
0.53	3.40	702	15	2.66	4.75

Table 4.12: Free and Total Chlorine Content for ALEW Stainless Steel, at 5V and 15V

NaCl Concentration (%)	pH	ORP (mV)	Voltage (V)	Free Chlorine (mg/L)	Total Chlorine (mg/L)
5 minutes					
0.53	8.87	-2	5	0.12	0.15
0.53	10.52	-71	15	0.16	0.19
7.5 minutes					
0.05	5.73	-6	5	0.10	0.11
0.05	6.89	-76	15	0.11	0.12
1.00	10.79	-71	5	0.14	0.16
1.00	11.52	-399	15	0.56	0.58
10 minutes					
0.53	10.52	-100	5	0.13	0.15
0.53	11.50	-888	15	0.23	0.27

4.6 Effects of different electrode types on the physio-chemical properties.

Jeong and others (2009) found out that the production of oxidants is influenced by the choice of electrode materials. To enhance the performance of electrolyzed water, there are many factors to be considered, one of them is choosing the right electrodes. An electrode should have the ability to withstand corrosion, erosion, catalyse the electrode reaction and have high electrical conductivity. Not only that, it also should not be expensive for industrial use, especially for Small and Medium Enterprise.

In this study, the types of electrodes used are Titanium and Stainless Steel. Stainless Steel is set at the anode, while Titanium and Stainless Steel is at cathode alternately. The order of electrode materials arranged in terms of the production of active chlorine was $Ti/IrO_2 > Ti/Pt-IrO_2 > BDD > Pt$. The type of material use at the electrode also influence the $HOCl, OCl$, and Cl_2 and the generation of reactive oxygen species including OH , O and H_2O_2 (Rahman et al., 2016). The most important parameter which influence the generation of oxidants and other species is choosing the right electrode material (Martinez-Huitle and Brillas 2008). Table 4.13 and 4.14 show the physio-chemical properties for electrodes Stainless Steel, Silver and Titanium 920 respectively.

Table 4.13: Physio-chemical properties of Titanium AcEW at 5, 10, 15 minutes.

NaCl Concentration (%)	Voltage (V)	Current (A)	pH	ORP (mV)	Free Chlorine (mg/L)	Total Chlorine (mg/L)
5 minutes						
0.05	10	0.10	5.08	417	0.20	0.21
0.53	15	1.75	3.68	801	2.80	2.09
1.00	10	1.79	4.33	636	1.65	2.26
7.5 minutes						
0.05	5	0.05	5.25	397	0.32	0.16
0.53	10	1.21	3.23	980	6.10	7.38
1.00	15	4.29	2.81	982	13.81	14.30
10 minutes						
0.05	10	0.24	4.38	401	0.13	0.15
0.53	15	2.50	2.77	999	4.57	4.88
1.00	10	2.75	3.30	514	2.08	2.21

Table 4.14: Physio-chemical properties of Stainless Steel AcEW at 5, 10, 15 minutes.

NaCl Concentration (%)	Voltage (V)	Current (A)	pH	ORP (mV)	Free Chlorine (mg/L)	Total Chlorine (mg/L)
5 minutes						
0.05	10	0.18	5.11	372	0.12	0.19
0.53	15	2.39	3.47	496	1.96	2.30
1.00	10	3.01	3.47	475	0.55	0.72
7.5 minutes						
0.05	5	0.06	4.61	381	0.16	0.21
0.53	10	1.28	3.42	583	1.31	1.69
1.00	15	4.21	2.94	782	1.53	1.76
10 minutes						
0.05	10	0.16	4.81	358	0.40	0.44
0.53	15	2.19	3.40	702	2.66	4.75
1.00	10	1.32	3.20	438	0.71	0.81

From the above results, the order for the performance of electrode types is form Stainless Steel/ Titanium > Stainless Steel/ Stainless Steel. The value obtained for production of free chlorine for Titanium is (13.81mg/L) while for Stainless Steel is (2.66 mg/L). It is expected that the ability of electrode to produce higher chlorine content are depending on the value of electrical conductivity of electrode. This is because electrode with higher electrical conductivity will produce higher chlorine content. This theory is well supported as Titanium has a higher electrical conductivity ($2.38 \times 10^6 \frac{S}{m}$) compared to Stainless Steel ($1.45 \times 10^6 \frac{S}{m}$).

4.7 Response Surface Methodology for Optimization usage of Electrolyzed Water.

For this study, Response Surface Methodology (RSM) and Box-Behnken design (BBD) were applied to evaluate the effects of three independent variable of (NaCl concentration, voltage and electrolysis time) on the four response of physical and chemical properties (pH, ORP, free chlorine and total chlorine) for two type of electrode materials (Titanium and Stainless Steel).

Based on preliminary data, BBD had three levels (-1,0,1) where it indicated NaCl concentration (0.05%, 0.53%, 1.0%), voltage (5V, 10V, 15V) and electrolysis time (5 minutes, 7.5 minutes and 10 minutes) respectively. For this study, the desirability function was selected to optimize process variable involve to achieve the highest free and total chlorine content. For BBD, a desirability approach finds the operating conditions that provide with the most suitable or 'desirable' response values after the preference of the goal of the four response as it set. The data were analysed by analysis of variance (ANOVA) using Design-Expert 11.0 program software by Stat-Ease, Inc Minneapolis, MN, USA.

For the optimization process, each goal is set as follow where for AcEW, the pH value needs to be minimized while oxidation reduction potential (ORP) and free chlorine production needs to be maximized. On the other hand, for AIEW the pH value needs to be maximized while oxidation reduction potential (ORP) and free chlorine production needs to be minimized. The combination of all these three factors are responsible for disinfecting the microbial activity by AcEW. The goals for each response are summarized as in Table 4.15 for AcEW and Table 4.16 for AIEW.

4.7.1 Development and analysis of the mathematical models.

For the development of mathematical models, the NND was investigated using design expert software. Multiple linear regression analyses of the experimental data yielded second order polynomials (quadratic) models for both AcEW and AIEW in predicting pH and free chlorine. While for ORP, analyses experimental data yielded linear and quadratic model for AcEW and AIEW.

For AcEW:

$$pH = 3.33 - 0.5950A - 0.5175B - 0.3475C + 0.0025AB - 0.0825AC - 0.1925BC + 0.6007A^2 + 0.1007B^2 + 0.3458C^2 \quad \text{(Equation 5.1)}$$

$$ORP = 932.20 + 143.88A + 165.25B + 8.63C + 42.75AB - 26.50AC + 42.75BC - 225.35A^2 - 60.10B^2 - 214.85C^2 \quad \text{(Equation 5.2)}$$

FC =

$$5.55 + 2.67A + 1.98B + 0.2688C + 2.26AB + 0.1250AC + 0.4375BC - 0.8620A^2 + 0.1155B^2 - 3.68C^2 \quad \text{(Equation 5.3)}$$

For AIEW

$$pH = 11.05 + 1.81A + 0.8663B + 1.21C - 0.4375AB - 1.03AC - 0.2250BC - 1.04A^2 - 0.9333B^2 - 0.3707C^2 \quad \text{(Equation 5.4)}$$

$$ORP = -594.20 - 174.00A - 158.38B - 132.13C + 6.75AB - 106.75AC - 183.50BC + 245.35A^2 + 242.60B^2 + 185.60C^2 \quad \text{(Equation 5.5)}$$

$$FC = 0.2180 + 0.0487A + 0.0225B - 0.0012C + 0.0150AB + 0.0275AC + 0.0050BC - 225.35A^2 - 60.10B^2 - 214.85C^2 \quad \text{(Equation 5.6)}$$



Where A represents the coded NaCl Concentration from -1 to 1: B represents the coded Voltage from -1 to 1: and C represents the coded Electrolysis time from -1 to 1.

Table 4.15: ANOVA result of P-value and R^2 for AcEW and AIEW.

Responses	AcEW		AIEW	
	P value	R^2	P value	R^2
pH	0.0015	0.9414	< 0.0001	0.9921
ORP	0.0369	0.8422	0.0096	0.8977
Free Chlorine	0.0934	0.7833	0.1139	0.7673

The mathematical model was evaluated by ANNOVA. Based on the low probability value ($P < 0.05$) indicates that it is significant. Regression coefficients (R^2), which should be > 0.80 for a good model fit. For AcEW, R^2 values for pH and ORP and are 0.9414 and 0.8422 respectively. The P value of AcEW for pH and ORP are 0.0015 and 0.0369 respectively. While for AIEW, R^2 values for pH and ORP are 0.9921 and 8977 respectively. The p value of AIEW for pH and ORP are < 0.0001 and 0.0096 respectively. Both pH and ORP value for AcEW and AIEW are significant.

Table 4.16 Criteria and limit of the numerical optimization of the responses of Titanium AcEW.

Responses(s)	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight
pH	Minimize	2.77	5.55	1	1
ORP (mV)	Maximize	397	1036	1	1
Free Chlorine (mg/L)	Maximize	0.13	13.81	1	1

Table 4.17 Criteria and limit of the numerical optimization of the responses of Titanium AlEW

Responses(s)	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight
pH	maximize	5.73	11.56	1	1
ORP (mV)	minimize	-797	322	1	1
Free Chlorine (mg/L)	minimize	0.04	0.25	1	1

The results show that electrode Titanium is selected out of the 2 types of electrode material since the free chlorine production is higher compared to Stainless Steel. From the BBD, multiple linear regression analyses of the experimental data yielded linear model for predicting pH, second order polynomial models for predicting ORP and free chlorine.

According to the numerical optimization, the desirability function generated the predicted optimum condition at maximum desirability index 0.932 (93.2%) for Titanium AcEW and maximum desirability index 0.495 (49.5%) for Titanium ALEW was obtained.

Table 4.18: List of desirability for Titanium AcEW

NaCl	Voltage	Electrolysis	pH	ORP	Free	Desirability	
Concentration		Time			Chlorine		
0.924	15.00	7.788	2.770	1035.990	11.221	0.932	Selected
0.978	15.000	8.114	2.760	1004.450	11.545	0.926	
0.995	15.000	8.036	2.794	997.437	11.688	0.923	
0.833	15.00	8.007	2.671	1062.46	10.490	0.912	

From the desirability approach obtained for Titanium AcEW, the predicted optimum condition for factors variable where 0.92wt% NaCl concentration, electrolysis time of 7.79min and voltage of 15.00V in order to gain optimum values of responses 2.77 pH, 1035.99 mV, 11.22mg/l free chlorine. If the desirability is approaching zero, it means that there are compromises are necessary to satisfy the criteria.

a.

pH

● Design points above predicted value

○ Design points below predicted value

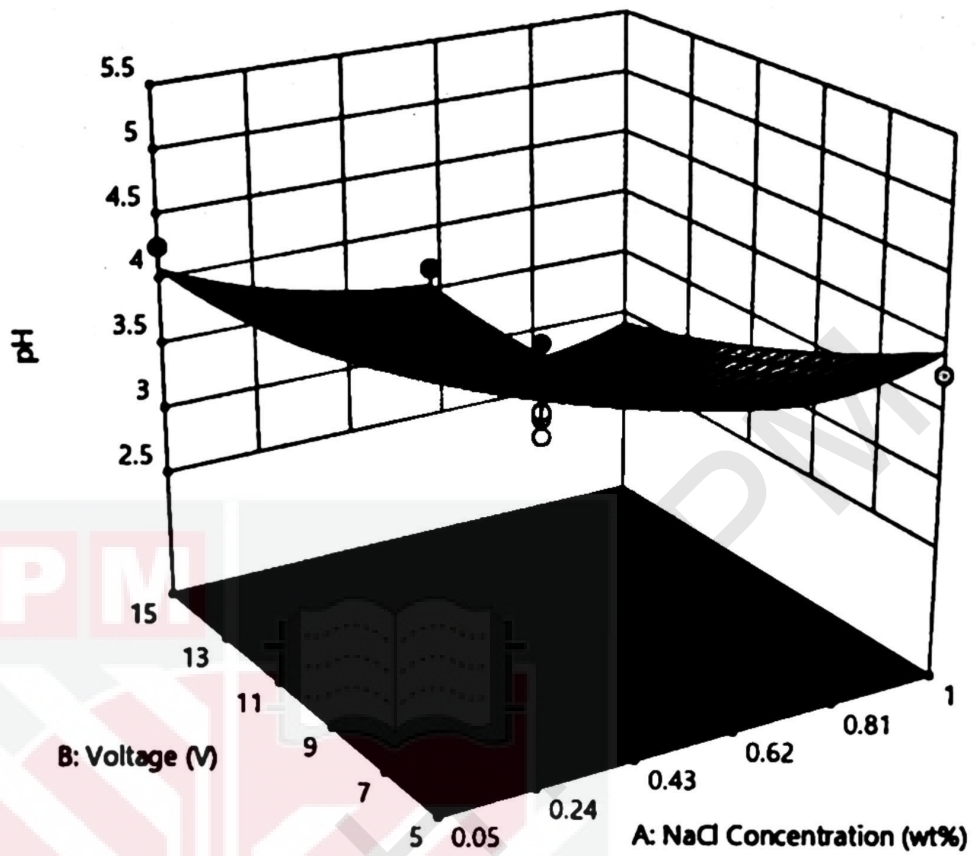
2.77  5.25

X1 = A: NaCl Concentration

X2 = B: Voltage

Actual Factor

C: Electrolysis Time = 7.5



b.

ORP (mV)

● Design points above predicted value

○ Design points below predicted value

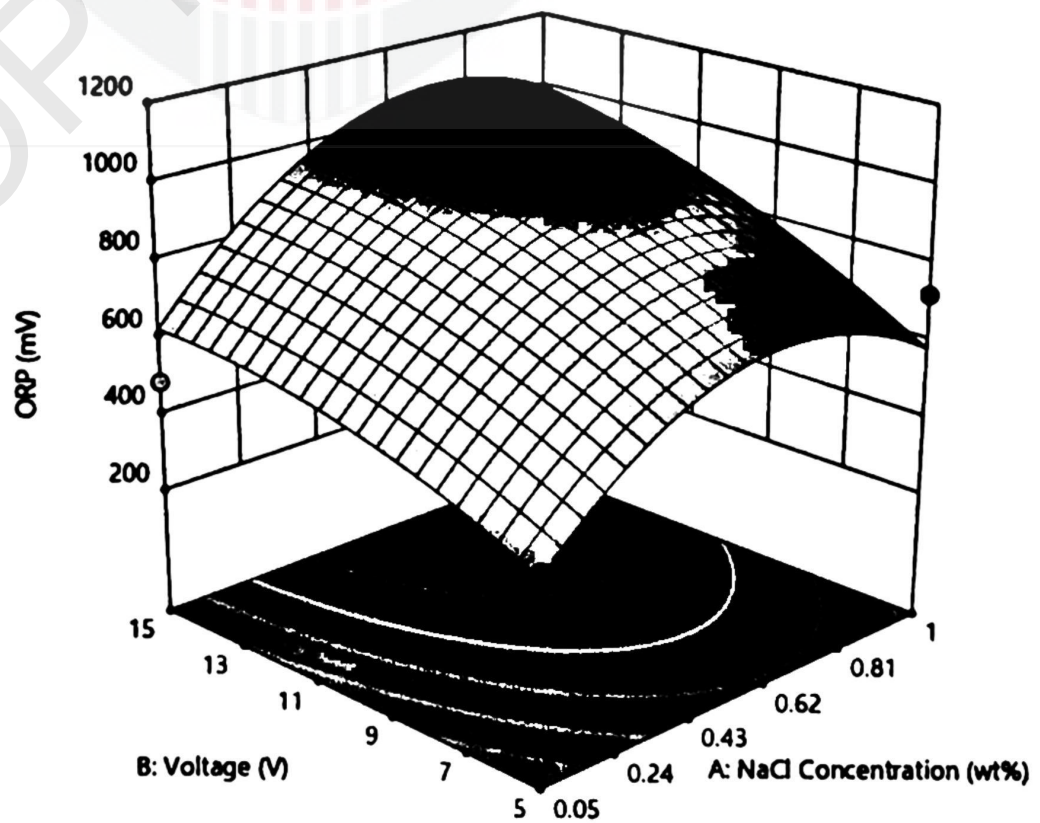
397  1036

X1 = A: NaCl Concentration

X2 = B: Voltage

Actual Factor

C: Electrolysis Time = 7.5



C.

Free chlorine (mg/l)
● Design points above predicted value
○ Design points below predicted value
0.13 ■ 13.81

X1 = A: NaCl Concentration
X2 = B: Voltage

Actual Factor
C: Electrolysis Time = 7.5

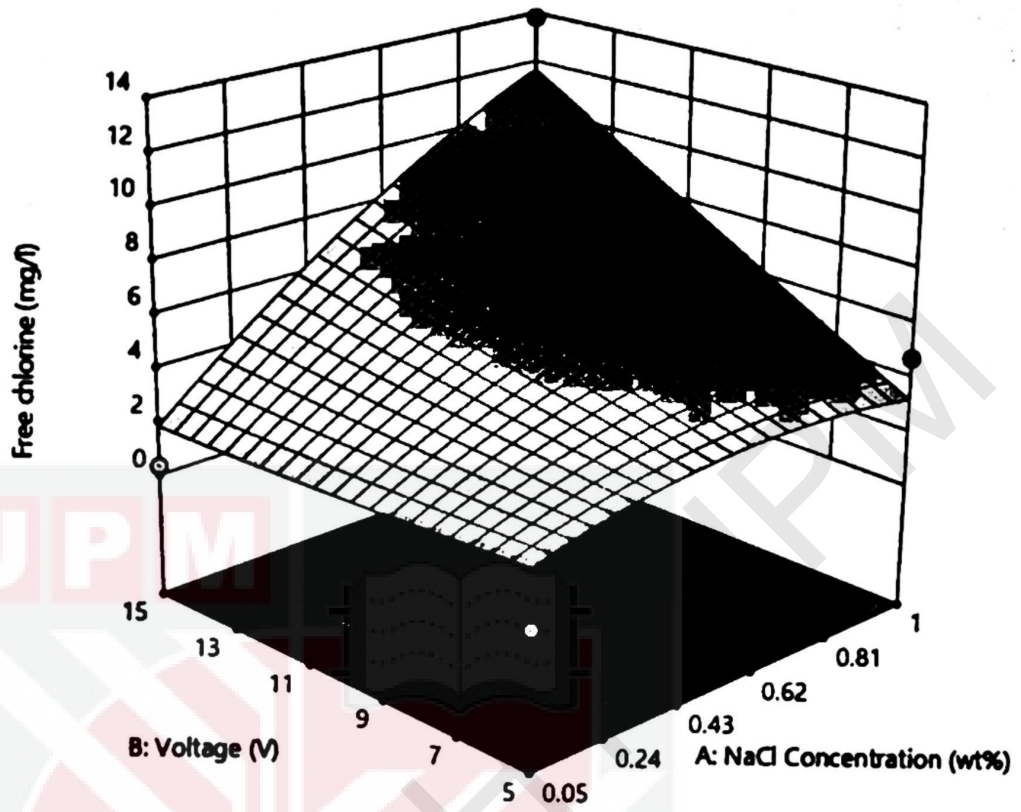



Figure 4.1: Analysis graph profile for Titanium AcEW of factors A: NaCL concentration and B: Voltage vs (a)pH, (b) Oxidation-reduction potential, (c) free chlorine.

Table 4.19: List of desirability of the solutions for Titanium ALEW.

NaCl Concentration	Voltage	Electrolysis Time	pH	ORP	Free Chlorine	Desirability	
0.250	13.460	10.000	11.270	-424.800	0.01	0.770	Selected
0.200	14.622	10.000	10.936	-346.812	0.076	0.762	
0.999	9.037	9.999	11.560	-502.611	0.163	0.672	
1.000	7.525	7.325	11.358	-377.08	0.178	0.590	

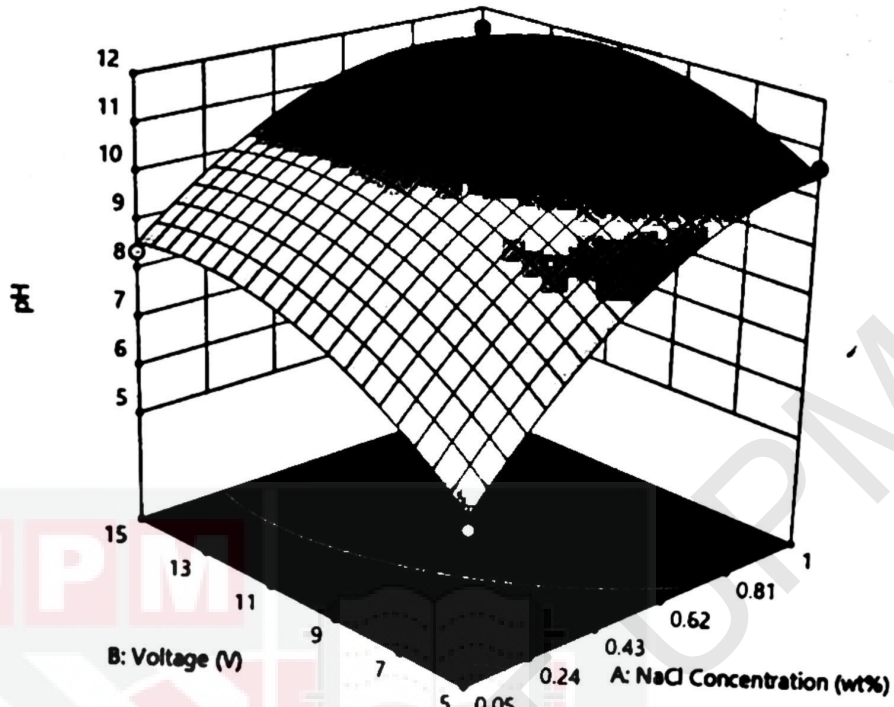
From the desirability approach obtained for Titanium AcEW, the predicted optimum condition for factors variable at 0.25wt% NaCl concentration, electrolysis time of 10.00 min and voltage of 13.46V in order to gain optimum values of responses 11.27pH, -424.80mV, 0.01mg/l free chlorine.

a.


pH
● Design points above predicted value
○ Design points below predicted value
5.73  11.56

X1 = A: NaCl Concentration
X2 = B: Voltage

Actual Factor
C: Electrolysis Time = 7.5

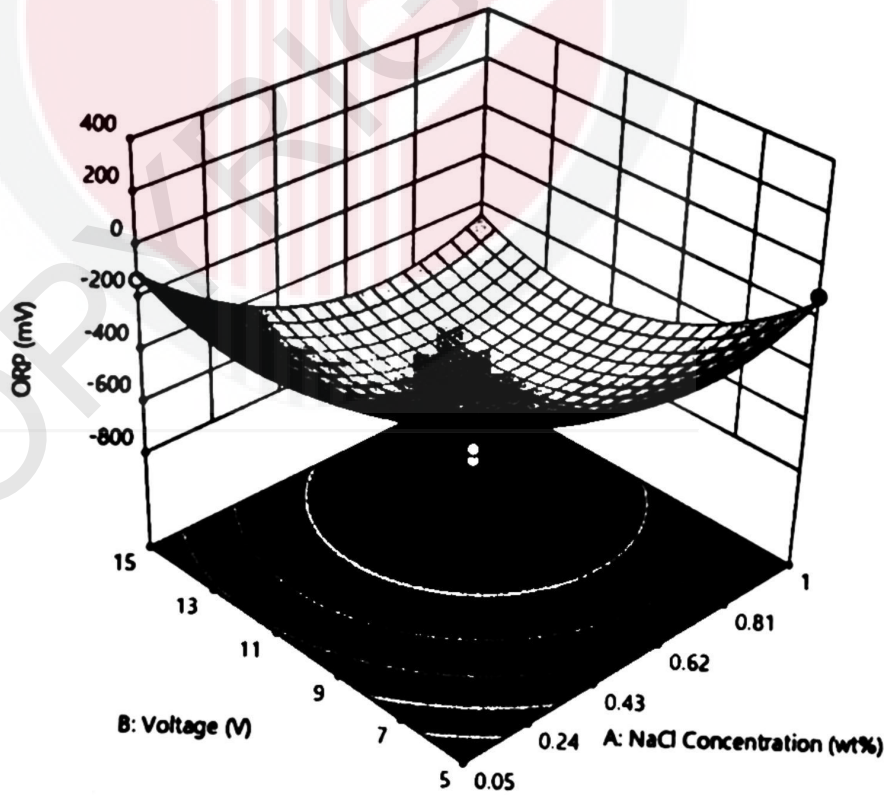


b.

ORP (mV)
● Design points above predicted value
○ Design points below predicted value
-797  322

X1 = A: NaCl Concentration
X2 = B: Voltage

Actual Factor
C: Electrolysis Time = 7.5



C.

Free Chlorine (mg/l)

● Design points above predicted value

○ Design points below predicted value

0.04 0.25

X1 = A: NaCl Concentration

X2 = B: Voltage

Actual Factor

C: Electrolysis Time = 7.5

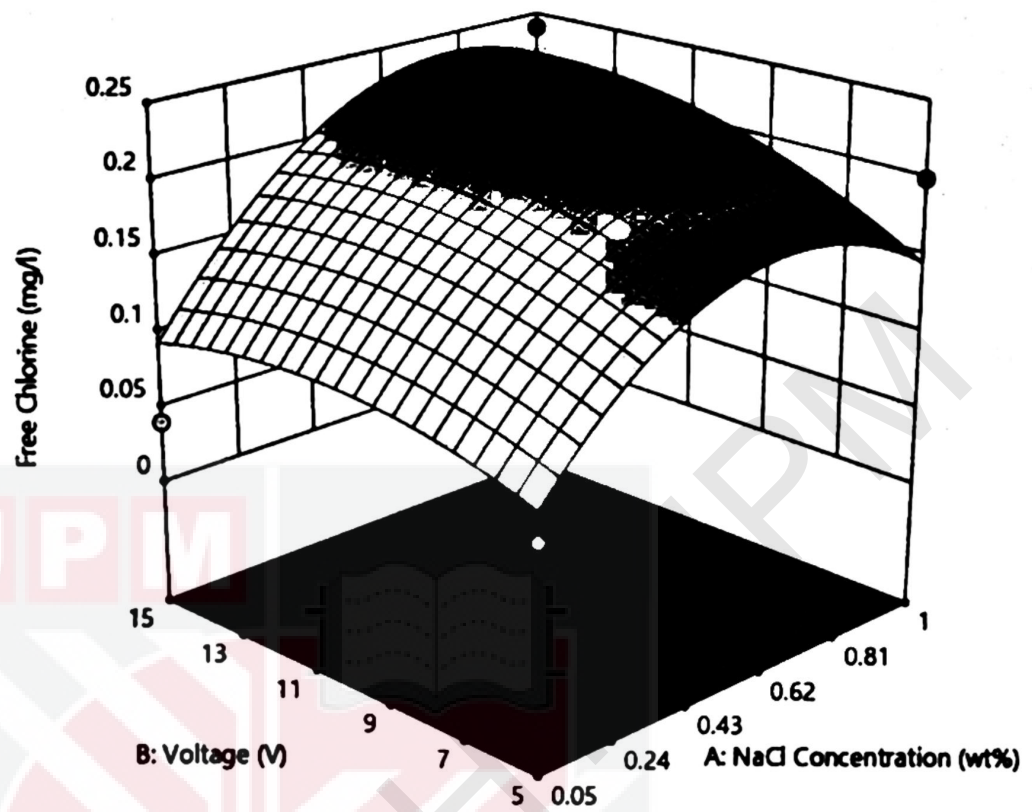


Figure 4.2: Analysis graph profile for Titanium AIEW of factors A: NaCl concentration and B: Voltage vs (a)pH, (b) Oxidation-reduction potential (c) free chlorine.



CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

In this chapter, a conclusion on the field of study and some suggestion or modification for future studies in the optimization of electrolyzed water with high cleaning effectiveness is given. The study is on producing AcEW and AEW at optimum conditions by using the revamped existing lab scale electrolyzing unit. To complete this study, the existing laboratory scale electrolyzing unit is revamped and to study on the effect of electrolyzing parameter (NaCl concentration, voltage, electrolysis time and materials of electrode) on physical and chemical properties (pH, ORP and free chlorine) of electrolyzed water produced.

5.1 Conclusions on design of experiment

Over the past few decades, electrolyzed water has gained recognition for its effective cleaning potential. In the food industry, effective cleaning system is required and compulsory to ensure the safety of the food product produced. The common problem faced by the food industry is that the use of commercial cleaning chemical which is very expensive and will harm the environment if not handle carefully. Thus, electrolyzed water has most of the advantage compared to other sanitizers which are low cost, less to none chemical residue, high efficacy and does not affects the quality of food products. Not only that, electrolyzed water is also considered as a green cleaner for it only made up of tap water and salt but have the cleaning ability of a sanitizer.

For this study, the experiment for determining the relation between electrolyzing parameter and physical and chemical properties is done by using a revamped laboratory scale electrolyzing unit. From this study, electrode Titanium is selected since it has the higher chlorine production where the chlorine contains Hypochlorous acid (HOCl). HOCl is a weak acid that forms when chlorine dissolves in water and it is a more powerful oxidizer than chlorine as it is a very effective sanitizing agent. RSM analysis indicated good agreement between the predicted and experimental values.

From the RSM and BBD, an optimal condition for AcEW is obtained where 0.92wt% NaCl concentration, electrolysis time of 7.79min and voltage of 15.00V in order to gain optimum values of responses 2.77 pH, 1035.99 mV, 11.22mg/l free chlorine. For AlEW, the optimal condition is obtained where 0.25wt% NaCl concentration, electrolysis time of 10.00 min and voltage of 13.46V in order to gain optimum values of responses 11.27pH, -424.80mV, 0.01mg/l free chlorine.

As a result from the revamp of the lab-scale electrolyzing unit, the free chlorine generation increased up to 18.86% and the current flow increased to 191.30% from the previous study.

5.2 Recommendation for future works

The trends of data obtained may not increase or decrease smoothly is mighty because probably both solution of AcEW and ALEW are not separated accordingly. The reason why there is a high concentration of chlorine in ALEW, which in theory should not be any or less than 0.05% is probably because AcEW solution got leaked into ALEW solution through the membrane holder gaps. The condition may have slight effect on the results obtained and to overcome and increase the improvements of this problem is by using a more efficient membrane holder without using any foreign metal. Plastic screws can be used to replace the previous membrane holder. Moreover, a slow stirrer should be added at the base of the electrolyzing unit for both AcEW and ALEW chamber. This ensures an even distribution solution before collecting them. Further modification and recommendation of this EW system can be performed to achieve optimal conditions.

Evaluation on effectiveness of electrolyzed water in eliminating foodborne pathogen is recommended for future work. This is due to this project was only perform optimization on typical cleaning chemical parameters.

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APPENDICES

TABLE OF RESULT

Table 1:Stainless Steel/Titanium (Acidic Electrolyzed water) Anode. -Repetition 1

NaCl Concent. (wt %)	Volt. (V)	Amp. (A)	pH		ORP (mV)		Free Chlorine (mg/l)		Total Chlorine (mg/l)		DO		Thermal Conductivity (Sm)		Temperature (°C)				
			Bef.	Aft.	Diff.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.		
5 Minutes																			
0.53	5	0.39	6.23	4.20	2.03	394	420	-26	0.43	0.50	7.1	7.5	-0.4	8.36	6.56	1.80	25.6	25.4	0.2
0.05	10	0.14	5.37	5.27	0.10	398	423	-25	0.23	0.25	7.7	6.3	1.4	1.14	0.70	0.44	25.5	25.3	0.2
1.00	10	2.18	5.27	5.24	0.03	374	360	14	0.13	0.14	6.7	5.9	0.8	15.80	16.92	-1.12	25.8	25.4	0.4
0.53	15	1.88	6.53	4.11	2.42	304	757	-453	1.98	0.14	6.7	6.0	0.7	11.11	6.73	4.38	25.5	25.3	0.2
7.5 Minutes																			
0.05	5	0.05	5.65	5.47	0.18	373	384	-11	0.50	0.17	7.0	6.4	0.6	1.25	1.07	0.18	25.3	25.2	0.1
1.00	5	0.80	6.64	4.48	2.16	284	421	-137	0.83	0.90	7.3	6.1	1.2	17.70	17.77	-0.07	26.2	25.7	0.5
0.53	10	1.20	6.19	4.05	2.14	368	500	-132	1.39	1.61	6.8	6.8	0.0	9.81	9.82	-0.01	26.3	25.9	0.4
0.53	10	1.50	6.02	3.75	2.27	320	847	-527	3.67	3.88	6.8	6.8	0.0	10.07	10.11	-0.04	28.4	27.4	1.0
0.53	10	1.35	5.73	3.52	2.21	326	902	-576	3.99	4.15	6.6	6.8	-0.2	9.95	10.08	-0.13	28.1	27.4	0.7
0.53	10	1.15	5.33	3.26	2.07	341	1019	-678	7.30	8.20	7.7	6.2	1.5	10.05	9.09	0.96	26.0	25.2	0.8
0.53	10	1.17	5.51	3.28	2.23	341	1019	-678	7.10	7.90	5.9	5.8	0.1	10.23	9.64	0.59	26.0	24.9	1.1
0.05	15	0.25	5.30	3.87	1.43	386	590	-204	0.51	0.60	6.5	5.8	0.7	1.29	1.09	0.20	24.8	23.8	1.0
1.00	15	3.85	5.27	3.36	1.91	361	827	-466	5.32	5.50	5.8	6.3	-0.5	18.81	20.00	-1.19	24.5	24.3	0.2
10 Minutes																			
0.53	5	0.43	5.28	4.71	0.57	393	369	24	0.18	0.20	6.7	6.9	-0.2	10.03	10.00	0.03	26.5	25.0	1.5
0.05	10	0.25	5.47	4.45	1.02	392	372	20	0.16	0.17	6.9	5.8	1.1	1.59	1.13	0.46	26.1	27.3	-1.2
1.00	10	2.68	5.29	4.10	1.19	324	362	-38	0.25	0.29	5.8	6.4	-0.6	18.22	16.65	1.57	28.8	27.4	1.4
0.53	15	2.36	5.55	3.24	2.31	382	914	-532	5.52	5.79	7.0	6.2	0.8	9.82	9.61	0.21	25.0	24.9	0.1

Table 2:Stainless Steel/Titanium (Alkaline Electrolyzed water) Cathode. -Repetition 1

NaCl Concent. (wt %)	Volt. (V)	Amp. (A)	pH			ORP (mV)			Free Chlorine (mg/l)	Total Chlorine (mg/l)	DO			Thermal Conductivity (S/m)			Temperature (°C)		
			Bef.	Aft.	Diff.	Bef.	Aft.	Diff.			Bef.	Aft.	Diff.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.
5 Minutes																			
0.53	5		6.23	7.72	-1.49	394	-323	717	0.15	0.17	7.1	6.7	0.4	8.36	7.82	0.54	25.6	25.4	0.2
0.05	10		5.37	5.48	-0.11	398	-358	756	0.17	0.14	7.7	6.8	0.9	1.14	1.19	-0.05	25.5	25.4	0.1
1.00	10		5.27	10.90	-5.63	374	-38	412	0.06	0.08	6.7	5.6	1.1	15.80	15.33	0.47	25.8	25.7	0.1
0.53	15		6.53	8.89	-2.36	304	189	115	0.21	0.23	6.7	5.5	1.2	11.11	11.25	-0.14	25.5	25.4	0.1
7.5 Minutes																			
0.05	5		5.65	6.17	-0.52	373	281	92	0.06	0.08	7.0	6.4	0.6	1.25	9.53	-8.28	25.3	25.4	-0.1
1.00	5		6.64	10.66	-4.02	284	-139	423	0.13	0.15	7.3	5.9	1.4	17.70	19.05	-1.35	26.2	26.3	-0.1
0.53	10		6.19	11.02	-4.83	368	-736	1104	0.15	0.16	6.8	5.8	1.0	9.81	10.29	-0.48	26.3	26.1	0.2
0.53	10		6.02	10.43	-4.41	320	-151	471	0.21	0.22	6.8	5.9	0.9	10.07	10.10	-0.03	28.4	28.0	0.4
0.53	10		5.73	11.06	-5.33	326	-795	1121	0.23	0.25	6.6	4.6	2.0	9.95	10.61	-0.66	28.1	28.7	-0.6
0.53	10		5.33	11.09	-5.76	341	-797	1138	0.20	0.21	7.7	4.9	2.8	10.05	11.65	-1.60	26.0	25.5	0.5
0.53	10		5.51	11.19	-5.68	341	-799	1140	0.19	0.23	5.9	4.9	1.0	10.23	10.58	-0.35	26.0	24.9	1.1
0.05	15		5.30	10.23	-4.93	386	45	341	0.07	0.08	6.5	5.9	0.6	1.29	1.19	0.10	24.8	24.1	0.7
1.00	15		5.27	11.36	-6.09	361	-175	536	0.16	0.19	5.8	7.0	-1.2	18.81	17.13	1.68	24.5	24.4	0.1
10 Minutes																			
0.53	5		5.28	10.21	-4.93	393	-100	493	0.06	0.06	6.7	7.4	-0.7	10.03	10.23	-0.20	26.5	25.6	0.9
0.05	10		5.47	10.18	-4.71	392	-52	444	0.05	0.05	6.9	5.8	1.1	1.59	1.40	0.19	26.1	27.2	-1.1
1.00	10		5.29	11.25	-5.96	324	-404	728	0.06	0.07	5.8	5.7	0.1	18.22	20.00	-1.78	28.8	28.2	0.6
0.53	15		5.55	11.41	-5.86	382	-416	798	0.21	0.25	7.0	5.5	1.5	9.82	9.23	0.59	25.0	25.6	-0.6

Table 3:Stainless Steel/Titanium (Acidic Electrolyzed water) Anode. -Repetition 2

NaCl Concent. (wt %)	Volt. (V)	Amp. (A)	pH			ORP (mV)			Free Chlorine (mg/l)	Total Chlorine (mg/l)	DO			Thermal Conductivity (S/cm)			Temperature (°C)		
			Bef.	Aft.	Diff.	Bef.	Aft.	Diff.			Bef.	Aft.	Diff.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.
5 Minutes																			
0.53	5	0.07	5.38	4.57	0.81	352	400	-48	0.14	0.16	6.7	6.2	0.5	10.00	9.82	0.18	25.2	24.0	1.2
0.05	10	0.05	5.30	4.89	0.41	636	411	225	0.16	0.17	6.9	6.6	0.3	1.06	1.33	-0.27	25.1	24.1	1.0
1.00	10	1.39	5.46	3.42	2.04	333	912	-579	3.17	4.38	6.8	6.4	0.4	17.17	18.89	-1.72	23.6	23.2	0.4
0.53	15	1.62	5.17	3.24	1.93	342	844	-502	3.62	4.03	6.8	6.4	0.4	9.23	9.85	-0.62	23.6	22.9	0.7
7.5 Minutes																			
0.05	5	0.04	5.17	5.03	0.14	390	409	-19	0.13	0.14	6.9	6.7	0.2	1.82	1.10	0.72	23.8	24.8	-1.0
1.00	5	0.48	5.11	3.08	2.03	388	1020	-632	8.70	9.10	6.8	6.5	0.3	17.37	18.17	-0.80	25.5	24.6	0.9
0.53	10	0.99	5.59	3.44	2.15	388	916	-528	3.17	3.96	6.8	6.1	0.7	9.98	9.81	0.17	25.3	24.5	0.8
0.53	10	1.01	6.24	3.11	3.13	319	1007	-688	5.10	5.90	6.6	6.3	0.3	9.80	10.03	-0.23	26.2	25.1	25.1
0.53	10	1.06	5.46	2.93	2.53	313	1057	-744	8.20	10.60	6.7	6.4	0.3	9.62	10.09	-0.47	26.9	25.9	1.0
0.53	10	1.18	5.44	2.82	2.62	342	1053	-711	8.40	12.50	6.9	6.3	0.6	9.96	10.39	-0.43	28.7	27.1	1.6
0.53	10	1.17	5.45	3.07	2.38	394	1001	-607	7.20	7.80	6.8	6.2	0.6	9.88	9.90	-0.02	26.2	25.0	1.2
0.05	15	0.40	5.46	4.66	0.80	355	384	-29	0.05	0.06	6.9	6.1	0.8	1.24	0.93	0.31	27.0	26.5	0.5
1.00	15	4.73	5.24	2.25	2.99	385	1136	-751	22.30	23.10	7.0	6.2	0.8	16.94	14.51	2.43	26.5	25.7	0.8
10 Minutes																			
0.53	5	0.54	6.12	3.78	2.34	350	469	-119	0.43	0.57	7.0	6.1	0.9	9.18	8.72	0.46	28.5	28.0	0.5
0.05	10	0.22	6.03	4.30	1.73	356	429	-73	0.09	0.12	6.9	6.0	0.9	1.21	0.94	0.27	27.5	27.0	0.5
1.00	10	2.81	6.14	2.49	3.65	369	665	-296	3.90	4.13	6.8	6.0	0.8	16.52	15.67	0.85	28.5	27.6	0.9
0.53	15	2.64	6.42	2.29	4.13	342	1083	-741	3.61	3.96	7.1	6.3	0.8	9.02	9.20	-0.18	27.8	26.2	1.6

Table 4:Stainless Steel/Titanium (Alkaline Electrolyzed water) Cathode. -Repetition 2

NaCl Concent. (wt %)	Volt. (V)	Amp. (A)	pH		ORP (mV)		Free Chlorine (mg/l)	Total Chlorine (mg/l)	DO		Thermal Conductivity (Sm)		Temperature (°C)						
			Bef.	Aft.	Diff.	Bef.			Aft.	Diff.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.			
5 Minutes																			
0.53	5	0.07	5.38	7.25	-1.87	352	185	167	0.05	0.05	6.7	6.3	0.4	10.00	9.90	0.10	25.2	24.4	0.8
0.05	10	0.05	5.30	6.10	-0.80	636	272	364	0.06	0.07	6.9	6.3	0.6	1.06	1.09	-0.03	25.1	24.1	1.0
1.00	10	1.39	5.46	11.19	-5.73	333	-182	515	0.11	0.12	6.8	0.2	6.6	17.17	18.83	-1.66	23.6	23.4	0.2
0.53	15	1.62	5.17	10.34	-5.17	342	-6	348	0.13	0.15	6.8	6.5	0.3	9.23	9.98	-0.75	23.6	23.2	0.4
7.5 Minutes																			
0.05	5	0.04	5.17	5.29	-0.12	390	362	28	0.05	0.05	6.9	6.8	0.1	1.82	1.11	0.71	23.8	24.9	-1.1
1.00	5	0.48	5.11	10.62	-5.51	388	-74	462	0.26	0.29	6.8	6.6	0.2	17.37	18.24	-0.87	25.5	25.0	0.5
0.53	10	0.99	5.59	11.18	-5.59	388	-361	749	0.17	0.19	6.8	5.8	1.0	9.98	10.57	-0.59	25.3	25.2	0.1
0.53	10	1.01	6.24	11.22	-4.98	319	-770	1089	0.27	0.28	6.6	6.3	0.3	9.80	10.41	-0.61	26.2	25.5	0.7
0.53	10	1.06	5.46	11.29	-5.83	313	-798	1111	0.26	0.29	6.7	6.5	0.2	9.62	10.55	-0.93	26.9	26.8	0.1
0.53	10	1.18	5.44	10.74	-5.30	342	-26	368	0.27	0.28	6.9	6.4	0.5	9.96	10.17	-0.21	28.7	27.5	1.2
0.53	10	1.17	5.45	11.28	-5.83	394	-705	1099	0.21	0.23	6.8	5.8	1.0	9.88	10.78	-0.90	26.2	25.7	0.5
0.05	15	0.40	5.46	6.54	-1.08	355	-283	638	0.00	0.00	6.9	5.7	1.2	1.24	0.95	0.28	27.0	26.6	0.4
1.00	15	4.73	5.24	11.73	-6.49	385	-866	1251	0.31	0.35	7.0	6.3	0.7	16.94	18.30	-1.36	26.5	26.1	0.4
10 Minutes																			
0.53	5	0.54	6.12	10.44	-4.32	350	-13	363	0.13	0.16	7.0	6.2	0.8	9.18	9.41	-0.23	28.5	28.2	0.3
0.05	10	0.22	6.03	10.38	-4.35	356	47	309	0.05	0.07	6.9	6.1	0.8	1.21	0.97	0.24	27.5	27.4	0.1
1.00	10	2.81	6.14	11.62	-5.48	369	-589	958	0.19	0.20	6.8	6.2	0.6	16.52	17.36	-0.84	28.5	28.6	-0.1
0.53	15	2.64	6.42	11.70	-5.28	342	-844	1186	0.17	0.18	7.1	6.2	0.9	9.02	9.29	-0.27	27.8	27.3	0.5

Table 5: Stainless Steel/Titanium (Acidic Electrolyzed water) Anode. -Mean

NaCl Concent. (wt %)	Volt. (V)	Amp. (A)	pH		ORP (mV)		Free Chlorine (mg/l)	Total Chlorine (mg/l)	DO		Thermal Conductivity (Sm)		Temperature (°C)						
			Bef.	Aft.	Diff.	Bef.			Aft.	Diff.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.			
5 Minutes																			
0.53	5	0.23	5.81	4.39	1.42	373	410	-37	0.29	0.33	6.9	6.9	0.0	9.18	8.19	0.99	25.4	24.7	0.7
0.05	10	0.10	5.34	5.08	0.26	517	417	100	0.20	0.21	7.3	7.3	0.9	1.10	1.02	0.08	25.3	24.7	0.6
1.00	10	1.79	5.37	4.33	1.04	354	636	-283	1.65	2.26	6.8	6.8	0.6	16.49	17.91	-1.42	24.7	24.3	0.4
0.53	15	1.75	5.85	3.68	2.18	323	801	-478	2.80	2.09	6.8	6.8	0.6	10.17	8.29	1.88	24.6	24.1	0.5
7.5 Minutes																			
0.05	5	0.05	5.41	5.25	0.16	382	397	-15	0.32	0.16	7.0	7.0	0.4	1.54	1.09	0.45	24.6	25.0	-0.4
1.00	5	0.64	5.88	3.78	2.10	336	721	-385	4.77	5.00	7.1	7.1	0.8	17.54	17.97	-0.44	25.9	25.2	0.7
0.53	10	1.10	5.89	3.75	2.15	378	708	-330	2.28	2.79	6.8	6.8	0.4	9.90	9.82	0.08	25.8	25.2	0.6
0.53	10	1.26	6.13	3.43	2.70	320	927	-608	4.39	4.89	6.7	6.7	0.2	9.94	10.07	-0.13	27.3	26.3	13.1
0.53	10	1.21	5.60	3.23	2.37	320	980	-660	6.10	7.38	6.7	6.7	0.0	9.79	10.09	-0.30	27.5	26.7	0.9
0.53	10	1.17	5.39	3.04	2.35	342	1036	-695	7.85	10.35	7.3	7.3	1.1	10.01	9.74	0.27	27.4	26.2	1.2
0.53	10	1.17	5.48	3.18	2.31	368	1010	-643	7.15	7.85	6.4	6.4	0.4	10.06	9.77	0.29	26.1	25.0	1.2
0.05	15	0.33	5.38	4.27	1.12	371	487	-117	0.28	0.33	6.7	6.7	0.8	1.26	1.01	0.25	25.9	25.2	0.8
1.00	15	4.29	5.26	2.81	2.45	373	982	-609	13.81	14.30	6.4	6.4	0.2	17.88	17.26	0.62	25.5	25.0	0.5
10 Minutes																			
0.53	5	0.49	5.70	4.25	1.46	372	419	-48	0.31	0.39	6.9	6.9	0.4	9.61	9.36	0.24	27.5	26.5	1.0
0.05	10	0.24	5.75	4.38	1.38	374	401	-27	0.13	0.15	6.9	6.9	1.0	1.40	1.04	0.36	26.8	27.1	-0.3
1.00	10	2.75	5.72	3.30	2.42	347	514	-167	2.08	2.21	6.3	6.3	0.1	17.37	16.16	1.21	28.7	27.5	1.2
0.53	15	2.50	5.99	2.77	3.22	362	999	-637	4.57	4.88	7.1	7.1	0.8	9.42	9.41	0.02	26.4	25.6	0.9

Table 6:Stainless Steel/Titanium (Alkaline Electrolyzed water) Cathode. -Mean

NaCl Concent. (wt %)	Volt. (V)	Amp. (A)	pH		ORP (mV)		Free Chlorine (mg/l)	Total Chlorine (mg/l)	DO		Thermal Conductivity (S/cm)		Temperature (°C)						
			Bef.	Aft.	Diff.	Bef.			Aft.	Diff.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.			
5 Minutes																			
0.53	5	0.23	5.81	7.49	-1.68	373	-69	442	0.10	0.11	6.9	6.5	0.4	9.18	8.86	0.32	25.4	24.9	0.5
0.05	10	0.10	5.34	5.79	-0.46	517	-43	560	0.12	0.11	7.3	6.6	0.8	1.10	1.14	-0.04	25.3	24.8	0.6
1.00	10	1.79	5.37	11.05	-5.68	354	-110	464	0.09	0.10	6.8	2.9	3.9	16.49	17.08	-0.59	24.7	24.6	0.2
0.53	15	1.75	5.85	9.62	-3.77	323	92	232	0.17	0.19	6.8	6.0	0.8	10.17	10.62	-0.45	24.6	24.3	0.3
7.5 Minutes																			
0.05	5	0.05	5.41	5.73	-0.32	382	322	60	0.06	0.07	7.0	6.6	0.4	1.54	5.32	-3.79	24.6	25.2	-0.6
1.00	5	0.64	5.88	10.64	-4.77	336	-107	443	0.20	0.22	7.1	6.3	0.8	17.54	18.65	-1.11	25.9	25.7	0.2
0.53	10	1.10	5.89	11.10	-5.21	378	-549	927	0.16	0.18	6.8	5.8	1.0	9.90	10.43	-0.53	25.8	25.7	0.2
0.53	10	1.26	6.13	10.83	-4.70	320	-461	780	0.24	0.25	6.7	6.1	0.6	9.94	10.26	-0.32	27.3	26.8	0.5
0.53	10	1.21	5.60	11.18	-5.58	320	-797	1116	0.25	0.27	6.7	5.6	1.1	9.79	10.58	-0.80	27.5	27.8	-0.3
0.53	10	1.17	5.39	10.92	-5.53	342	-412	753	0.24	0.25	7.3	5.7	1.7	10.01	10.91	-0.90	27.4	26.5	0.9
0.53	10	1.17	5.48	11.24	-5.76	368	-752	1120	0.20	0.23	6.4	5.4	1.0	10.06	10.68	-0.62	26.1	25.3	0.8
0.05	15	0.33	5.38	8.39	-3.01	371	-119	490	0.04	0.04	6.7	5.8	0.9	1.26	1.07	0.19	25.9	25.4	0.5
1.00	15	4.29	5.26	11.55	-6.29	373	-521	894	0.24	0.27	6.4	6.7	-0.3	17.88	17.72	0.16	25.5	25.3	0.3
10 Minutes																			
0.53	5	0.49	5.70	10.33	-4.63	372	-57	428	0.10	0.11	6.9	6.8	0.0	9.61	9.82	-0.22	27.5	26.9	0.6
0.05	10	0.24	5.75	10.28	-4.53	374	-3	377	0.05	0.06	6.9	6.0	1.0	1.40	1.18	0.22	26.8	27.3	-0.5
1.00	10	2.75	5.72	11.44	-5.72	347	-497	843	0.13	0.14	6.3	6.0	0.4	17.37	18.68	-1.31	28.7	28.4	0.3
0.53	15	2.50	5.99	11.56	-5.57	362	-630	992	0.19	0.22	7.1	5.9	1.2	9.42	9.26	0.16	26.4	26.5	-0.1

Table 7:Stainless Steel/Stainless Steel (Acidic Electrolyzed water) Anode. -Repetition 1

NaCl Concent. (wt %)	Volt. (V)	Amp. (A)	pH			ORP (mV)			Free Chlorine (mg/l)	Total Chlorine (mg/l)	DO			Thermal Conductivity (S _m)			Temperature (°C)		
			Bef.	Aft.	Diff.	Bef.	Aft.	Diff.			Bef.	Aft.	Diff.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.
5 Minutes																			
0.53	5	0.58	6.22	4.99	1.23	299	341	-42	0.13	0.17	5.9	4.7	1.2	8.52	9.36	-0.84	28.6	27.6	1.0
0.05	10	0.18	6.29	5.06	1.23	306	408	-102	0.13	0.21	4.9	4.2	0.7	1.28	0.92	0.36	29.0	28.1	0.9
1.00	10	3.61	5.44	3.38	2.06	385	522	-137	0.37	0.62	4.1	3.8	0.3	15.28	16.47	-1.19	29.5	28.8	0.7
0.53	15	2.52	6.73	3.82	2.91	304	362	-58	0.55	0.77	3.6	3.7	-0.1	8.91	9.02	-0.11	28.5	28.2	0.3
7.5 Minutes																			
0.05	5	0.07	6.60	5.28	1.32	297	361	-64	0.12	0.19	5.2	4.7	0.5	1.52	1.23	0.29	26.6	26.5	0.1
1.00	5	2.42	5.16	3.38	1.78	367	443	-76	0.82	0.96	4.6	4.2	0.4	16.22	15.16	1.06	26.5	26.4	0.1
0.53	10	1.11	5.90	3.45	2.45	309	477	-168	0.68	0.75	4.6	4.7	-0.1	9.02	8.33	0.69	26.5	26.3	0.2
0.53	10	1.25	6.58	3.79	2.79	280	736	-456	2.59	3.37	4.7	4.0	0.7	8.56	8.51	0.05	26.8	26.4	0.4
0.53	10	1.19	6.72	3.66	3.06	313	852	-539	2.47	3.21	4.7	5.8	-1.1	8.56	8.74	-0.18	26.5	26.3	0.2
0.53	10	1.35	6.42	3.68	2.74	368	955	-587	4.21	4.38	4.1	4.2	-0.1	8.74	8.62	0.12	25.8	25.9	-0.1
0.53	10	1.27	5.66	3.62	2.04	398	977	-579	2.65	3.40	4.7	3.7	1.0	8.62	8.44	0.18	25.8	25.6	0.2
0.05	15	0.28	5.69	4.32	1.37	460	489	-29	0.24	0.33	4.6	4.4	0.2	1.00	0.92	0.08	28.7	28.3	0.4
1.00	15	4.54	5.40	3.21	2.19	423	449	-26	0.61	1.01	5.2	4.7	0.5	15.45	16.62	-1.17	28.9	27.9	1.0
10 Minutes																			
0.53	5	0.57	6.28	4.56	1.72	268	275	-7	0.54	0.55	4.3	4.2	0.1	8.69	8.70	-0.01	28.8	27.3	1.5
0.05	10	0.17	5.97	5.14	0.83	257	332	-75	0.22	0.23	4.8	3.8	1.0	1.23	9.08	-7.85	27.1	26.4	0.7
1.00	10	2.47	5.43	3.24	2.19	301	392	-91	0.89	1.00	4.7	4.6	0.1	15.19	16.35	-1.16	25.6	25.4	0.2
0.53	15	2.43	5.86	3.26	2.60	253	969	-716	4.99	5.53	4.4	4.4	0.0	8.56	8.77	-0.21	26.4	25.4	1.0

Table 8:Stainless Steel/Stainless Steel (Alkaline Electrolyzed water) Cathode. -Repetition 1

NaCl Concent. (wt %)	Volt. (V)	Amp. (A)	pH		ORP (mV)		Free Chlorine (mg/l)	Total Chlorine (mg/l)	DO		Thermal Conductivity (Sm)		Temperature (°C)					
			Bef.	Aft.	Diff.	Bef.			Aft.	Diff.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.		
5 Minutes																		
0.53	5	0.58	6.22	10.49	-4.27	299	-44	343	0.14	0.20	5.9	5.0	0.9	8.24	8.52	28.6	27.6	1.0
0.05	10	0.18	6.29	6.17	0.12	306	343	-37	0.08	0.15	4.9	3.7	1.2	0.96	1.28	29.0	28.1	0.9
1.00	10	3.61	5.44	10.94	-5.50	385	-180	565	0.08	0.18	4.1	3.9	0.2	15.28	16.36	29.5	28.8	0.7
0.53	15	2.52	6.73	10.70	-3.97	304	-52	356	0.14	0.18	3.6	3.9	-0.3	8.82	8.91	28.5	28.2	0.3
7.5 Minutes																		
0.05	5	0.07	6.60	6.17	0.43	297	356	-59	0.11	0.13	4.6	4.8	-0.2	1.52	1.52	26.6	26.5	0.1
1.00	5	2.42	5.16	10.95	-5.79	367	-132	499	0.14	0.17	5.2	4.4	0.8	16.22	17.82	26.5	26.3	0.2
0.53	10	1.11	5.90	11.09	-5.19	309	-497	806	0.20	0.10	4.6	3.1	1.5	9.02	9.51	26.5	26.3	0.2
0.53	10	1.25	6.58	10.97	-4.39	280	-262	542	0.18	0.27	4.6	3.8	0.8	8.56	9.04	26.8	26.5	0.3
0.53	10	1.19	6.72	10.98	-4.26	313	-359	672	0.16	0.19	4.7	3.7	1.0	8.56	9.15	26.5	26.5	0.0
0.53	10	1.35	6.42	11.02	-4.60	368	-170	538	0.14	0.15	4.7	4.0	0.7	8.74	8.74	25.8	25.9	-0.1
0.53	10	1.27	5.66	11.00	-5.34	398	-73	471	0.13	0.17	4.1	4.2	-0.1	8.62	9.30	25.8	25.8	0.0
0.05	15	0.28	5.69	7.23	-1.54	460	190	270	0.09	0.11	4.7	4.0	0.7	1.00	1.00	28.7	28.3	0.4
1.00	15	4.54	5.40	11.30	-5.90	423	-798	1221	0.69	0.71	4.6	3.7	0.9	15.45	17.27	28.9	28.8	0.1
10 Minutes																		
0.53	5	0.57	6.28	10.59	-4.31	268	-105	373	0.15	0.16	4.3	4.1	0.2	8.69	8.84	28.8	27.6	1.2
0.05	10	0.17	5.97	7.16	-1.19	257	169	88	0.10	0.13	4.8	4.2	0.6	1.23	1.23	27.1	27.0	0.1
1.00	10	2.47	5.43	11.30	-5.87	301	-812	1113	0.19	0.22	4.7	3.6	1.1	15.19	17.02	25.6	25.7	-0.1
0.53	15	2.43	5.86	11.29	-5.43	253	-775	1028	0.34	0.41	4.4	3.5	0.9	8.56	9.43	26.4	26.0	0.4

Table 9: Stainless Steel/Stainless Steel (Acidic Electrolyzed water) Anode. -Repetition 2

NaCl Concentr. (wt %)	Volt. (V)	Amp. (A)	pH			ORP (mV)			Free Chlorine (mg/l)	Total Chlorine (mg/l)	DO			Thermal Conductivity (S/cm)			Temperature (°C)		
			Bef.	Aft.	Diff.	Bef.	Aft.	Diff.			Bef.	Aft.	Diff.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.
5 Minutes																			
0.53	5	2.20	6.63	4.67	1.96	267	275	-8	0.18	0.20	5.9	5.6	0.3	8.87	8.51	0.36	27.4	27.1	0.3
0.05	10	0.17	6.22	5.16	1.06	253	335	-82	0.11	0.16	6.2	4.8	1.4	1.12	1.15	-0.03	26.7	26.4	0.3
1.00	10	2.41	5.38	3.55	1.83	391	428	-37	0.73	0.81	5.4	5.8	-0.4	14.59	15.70	-1.11	28.3	27.8	0.5
0.53	15	2.26	5.46	3.11	2.35	340	630	-290	3.36	3.83	6.4	6.6	-0.2	8.22	11.19	-2.97	26.4	26.5	-0.1
7.5 Minutes																			
0.05	5	0.05	4.75	3.94	0.81	390	400	-10	0.20	0.22	6.5	6.7	-0.2	1.50	5.50	-4.00	26.2	25.9	0.3
1.00	5	0.99	5.16	3.78	1.38	370	376	-6	0.37	0.45	5.3	5.9	-0.6	16.32	14.83	1.49	26.0	25.7	0.3
0.53	10	1.21	5.57	3.08	2.49	310	871	-561	5.20	5.69	6.1	7.0	-0.9	8.74	7.79	0.95	26.2	26.2	0.0
0.53	10	1.05	5.76	3.98	1.78	294	510	-216	0.94	1.23	6.6	5.3	1.3	7.29	6.13	1.16	26.4	26.3	25.1
0.53	10	1.36	5.39	3.17	2.22	380	313	67	0.14	0.17	6.3	5.2	1.1	8.96	7.79	1.17	26.3	26.1	0.2
0.53	10	1.58	5.47	3.17	2.30	431	957	-526	3.17	3.94	5.9	5.2	0.7	8.63	9.12	-0.49	29.0	28.1	0.9
0.53	10	0.56	5.86	4.64	1.22	302	435	-133	0.41	0.51	6.2	6.0	0.2	9.72	9.58	0.14	29.8	29.5	0.3
0.05	15	0.27	5.07	3.68	1.39	308	427	-119	0.24	0.30	6.6	6.0	0.6	12.90	10.48	2.42	28.4	27.2	1.2
1.00	15	3.88	5.62	2.67	2.95	342	1115	-773	2.45	2.50	6.5	7.9	-1.4	17.00	14.02	2.98	27.0	27.5	-0.5
10 Minutes																			
0.53	5	0.35	4.45	4.90	-0.45	298	347	-49	0.26	0.33	7.6	5.9	1.7	8.55	7.18	1.37	28.8	28.0	0.8
0.05	10	0.14	5.97	4.47	1.50	344	383	-39	0.58	0.64	7.1	6.0	1.1	12.66	7.13	5.53	26.7	25.6	1.1
1.00	10	0.17	5.37	3.16	2.21	385	483	-98	0.52	0.61	7.0	6.0	1.0	16.51	13.68	2.83	26.5	26.4	0.1
0.53	15	1.95	4.73	3.54	1.19	345	435	-90	0.33	3.96	3.9	4.8	-0.9	9.15	11.70	-2.55	26.4	26.2	0.2

Table 10:Stainless Steel/Stainless Steel (Alkaline Electrolyzed water) Cathode. -Repetition 2

NaCl Spercent. (wt %)	Volt. (V)	Amp. (A)	pH		ORP (mV)		Free Chlorine (mg/l)	Total Chlorine (mg/l)	DO		Thermal Conductivity (S/cm)		Temperature (°C)						
			Bef.	Aft.	Diff.	Bef.			Aft.	Diff.	Bef.	Aft.	Bef.	Aft.	Bef.	Aft.	Diff.		
5 Minutes																			
0.53	5	2.20	6.63	7.25	-0.62	267	40	227	0.10	0.10	5.9	5.2	0.7	8.87	8.71	0.16	27.4	27.1	0.3
0.05	10	0.17	6.22	6.10	0.12	253	161	92	0.08	0.09	6.2	5.2	1.0	1.12	0.98	0.14	26.7	26.6	0.1
1.00	10	2.41	5.38	11.19	-5.81	391	-224	615	0.08	0.11	5.4	5.8	-0.4	14.59	15.77	-1.18	28.3	27.9	0.4
0.53	15	2.26	5.46	10.34	-4.88	340	-90	430	0.17	0.19	6.4	4.4	2.0	8.22	9.98	-1.76	26.4	26.4	0.0
7.5 Minutes																			
0.05	5	0.05	4.75	5.29	-0.54	390	-367	757	0.08	0.09	6.5	6.8	-0.3	1.50	1.29	0.22	26.2	26.0	0.2
1.00	5	0.99	5.16	10.62	-5.46	370	-9	379	0.14	0.14	5.3	6.4	-1.1	16.32	17.20	-0.88	26.0	25.9	0.1
0.53	10	1.21	5.57	11.18	-5.61	310	-155	465	0.15	0.17	6.1	6.7	-0.6	8.74	10.47	-1.73	26.2	25.0	1.2
0.53	10	1.05	5.12	11.22	-6.10	294	59	235	0.14	0.17	6.6	5.8	0.8	7.29	9.96	-2.67	26.4	26.3	0.1
0.53	10	1.36	5.89	11.29	-5.40	380	-48	428	0.13	0.15	6.3	5.8	0.5	8.96	7.87	1.09	26.3	26.2	0.1
0.53	10	1.58	5.47	10.74	-5.27	431	-508	939	0.15	0.16	5.9	3.9	2.0	8.63	9.57	-0.94	29.0	28.7	0.3
0.53	10	0.56	6.56	11.28	-4.72	302	-108	410	0.17	0.18	6.2	6.4	-0.2	9.72	8.21	1.51	29.8	29.5	0.3
0.05	15	0.27	5.07	6.54	-1.47	308	-39	347	0.12	0.13	6.6	6.4	0.2	12.90	10.13	2.77	28.4	27.1	1.3
1.00	15	3.88	5.62	11.73	-6.11	342	0	342	0.43	0.44	6.5	6.0	0.5	17.00	20.00	-3.00	27.0	26.7	0.3
10 Minutes																			
0.53	5	0.35	4.45	10.44	-5.99	298	-97	395	0.11	0.13	7.6	5.2	2.4	8.55	9.41	-0.86	28.8	28.2	0.6
0.05	10	0.14	5.97	10.38	-4.41	344	-118	462	0.12	0.15	7.1	8.8	-1.7	12.66	12.40	0.26	26.7	26.5	0.2
1.00	10	0.17	5.37	11.62	-6.25	385	-73	458	0.12	0.14	7.0	5.6	1.4	16.51	20.00	-3.49	26.5	26.4	0.1
0.53	15	1.95	4.73	11.70	-6.97	345	-1000	1345	0.11	0.13	3.9	5.7	-1.8	9.15	6.20	2.95	26.4	26.6	-0.2

Table 11:Stainless Steel/Stainless Steel (Acidic Electrolyzed water) Anode. -Mean

NaCl Source (wt %)	Volt. (V)	Amp. (A)	pH		ORP (mV)		Free Chlorine (mg/l)	Total Chlorine (mg/l)	DO		Thermal Conductivity (S/cm)		Temperature (°C)						
			Bef.	Aft.	Diff.	Bef.			Aft.	Diff.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.			
5 Minutes																			
0.53	5	1.39	6.43	4.83	1.60	283	308	-25	0.16	0.19	5.9	5.2	0.8	8.70	8.94	-0.24	28.0	27.4	0.6
0.05	10	0.18	6.26	5.11	1.15	280	372	-92	0.12	0.19	5.6	4.5	1.1	1.20	1.03	0.17	27.9	27.3	0.6
1.00	10	3.01	5.41	3.47	1.95	388	475	-87	0.55	0.72	4.8	4.8	0.0	14.94	16.09	-1.15	28.9	28.3	0.6
0.53	15	2.39	6.10	3.47	2.63	322	496	-174	1.96	2.30	5.0	5.2	-0.2	8.57	10.11	-1.54	27.5	27.4	0.1
7.5 Minutes																			
0.05	5	0.06	5.68	4.61	1.07	344	381	-37	0.16	0.21	5.6	5.7	-0.2	1.51	3.36	-1.85	26.4	26.2	0.2
1.00	5	1.71	5.16	3.58	1.58	369	410	-41	0.60	0.71	5.3	5.3	-0.1	16.27	15.00	1.28	26.3	26.1	0.2
0.53	10	1.16	5.74	3.27	2.47	310	674	-365	2.94	3.22	5.4	5.6	-0.3	8.88	8.06	0.82	26.4	26.3	0.1
0.53	10	1.15	6.17	3.89	2.29	287	623	-336	1.77	2.30	5.6	5.0	0.6	7.93	7.32	0.61	26.6	26.4	12.8
0.53	10	1.28	6.06	3.42	2.64	347	583	-236	1.31	1.69	5.5	4.6	0.9	8.76	8.27	0.50	26.4	26.2	0.2
0.53	10	1.47	5.95	3.43	2.52	400	956	-557	3.69	4.16	5.3	5.5	-0.2	8.69	8.87	-0.18	27.4	27.0	0.4
0.53	10	0.92	5.76	4.13	1.63	350	706	-356	1.53	1.96	5.2	5.1	0.0	9.17	9.01	0.16	27.8	27.6	0.3
0.05	15	0.28	5.38	4.00	1.38	384	458	-74	0.24	0.32	5.7	4.9	0.8	6.95	5.70	1.25	28.6	27.8	0.8
1.00	15	4.21	5.51	2.94	2.57	383	782	-400	1.53	1.76	5.6	6.2	-0.6	16.23	15.32	0.90	28.0	27.7	0.3
10 Minutes																			
0.53	5	0.46	5.37	4.73	0.64	283	311	-28	0.40	0.44	6.0	5.1	0.9	8.62	7.94	0.68	28.8	27.7	1.2
0.05	10	0.16	5.97	4.81	1.17	301	358	-57	0.40	0.44	6.0	4.9	1.1	6.95	8.11	-1.16	26.9	26.0	0.9
1.00	10	1.32	5.40	3.20	2.20	343	438	-95	0.71	0.81	5.9	5.3	0.6	15.85	15.02	0.84	26.1	25.9	0.2
0.53	15	2.19	5.30	3.40	1.90	299	702	-403	2.66	4.75	4.2	4.6	-0.5	8.86	10.24	-1.38	26.4	25.8	0.6

Table 12:Stainless Steel/Stainless Steel (Alkaline Electrolyzed water) Cathode. -Mean

NaCl Source (wt.%)	Volt. (V)	Amp. (A)	pH			ORP (mV)			Free Chlorine (mg/l)	Total Chlorine (mg/l)	DO			Thermal Conductivity (S/cm)			Temperature (°C)		
			Bef.	Aft.	Diff.	Bef.	Aft.	Diff.			Bef.	Aft.	Diff.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.
5 Minutes																			
0.53	5	1.39	6.43	8.87	-2.45	283	-2	285	0.12	0.15	5.9	5.1	0.8	8.70	8.48	0.22	28.0	27.4	0.6
0.05	10	0.18	6.26	6.14	0.12	280	252	28	0.08	0.12	5.6	4.5	1.1	1.20	0.97	0.23	27.9	27.4	0.5
1.00	10	3.01	5.41	11.07	-5.66	388	-202	590	0.08	0.15	4.8	4.9	-0.1	14.94	16.07	-1.13	28.9	28.4	0.6
0.53	15	2.39	6.10	10.52	-4.43	322	-71	393	0.16	0.19	5.0	4.2	0.9	8.57	9.40	-0.84	27.5	27.3	0.2
7.5 Minutes																			
0.05	5	0.06	5.68	5.73	-0.06	344	-6	349	0.10	0.11	5.6	5.8	-0.3	1.51	5.38	-3.87	26.4	26.3	0.2
1.00	5	1.71	5.16	10.79	-5.63	369	-71	439	0.14	0.16	5.3	5.4	-0.2	16.27	17.51	-1.24	26.3	26.1	0.2
0.53	10	1.16	5.74	11.14	-5.40	310	-326	636	0.18	0.14	5.4	4.9	0.5	8.88	9.99	-1.11	26.4	25.7	0.7
0.53	10	1.15	5.85	11.10	-5.25	287	-102	389	0.16	0.22	5.6	4.8	0.8	7.93	9.50	-1.58	26.6	26.4	0.2
0.53	10	1.28	6.31	11.14	-4.83	347	-204	550	0.15	0.17	5.5	4.8	0.8	8.76	8.51	0.25	26.4	26.4	0.1
0.53	10	1.47	5.95	10.88	-4.94	400	-339	739	0.15	0.16	5.3	4.0	1.4	8.69	9.34	-0.65	27.4	27.3	0.1
0.53	10	0.92	6.11	11.14	-5.03	350	-91	441	0.15	0.18	5.2	5.3	-0.2	9.17	8.76	0.41	27.8	27.7	0.2
0.05	15	0.28	5.38	6.89	-1.51	384	76	309	0.11	0.12	5.7	5.2	0.5	6.95	5.54	1.41	28.6	27.7	0.8
1.00	15	4.21	5.51	11.52	-6.01	383	-399	782	0.56	0.58	5.6	4.9	0.7	16.23	18.64	-2.41	28.0	27.8	0.2
10 Minutes																			
0.53	5	0.46	5.37	10.52	-5.15	283	-101	384	0.13	0.15	6.0	4.7	1.3	8.62	9.13	-0.51	28.8	27.9	0.9
0.05	10	0.16	5.97	8.77	-2.80	301	26	275	0.11	0.14	6.0	6.5	-0.6	6.95	6.68	0.26	26.9	26.8	0.2
1.00	10	1.32	5.40	11.46	-6.06	343	-443	786	0.16	0.18	5.9	4.6	1.3	15.85	18.51	-2.66	26.1	26.1	0.0
0.53	15	2.19	5.30	11.50	-6.20	299	-888	1187	0.23	0.27	4.2	4.6	-0.5	8.86	7.82	1.04	26.4	26.3	0.1