UNIVERSITI PUTRA MALAYSIA

STUDY ON EFFECT OF ELECTRODE MATERIALS ON GENERATION OF ELECTROLYZED WATER FOR GREEN SANITATION SOLUTIONS

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ABSTRACT

The aim of this project is to investigate the effect of electrode materials (Titanium-Stainless Steel 316, Stainless Steel 316-Nickel and Stainless Steel 316-Aluminium Alloy) on the generation of the electrolyzed water as a green cleaner for food industry application. Electrolyzed water is one of the latest green cleaning and sanitizing solutions that offers cost savings, offer greater convenience in finding alternatives and environmental friendly sanitation solution. Acidic electrolyzed water (AcEW) have strong bactericidal efficacy on numerous microorganisms. Meanwhile, Alkaline electrolyzed water (AlEW) has a potential as a cleaning medium alternative for alkaline cleaning. Several electrodes pairing were used during the electrolysis study. The results suggest that Titanium- Stainless Steel 316 is the best electrodes pairing in generating the electrolyzed water. Effect of electrolyzing parameters (NaC1 concentration, voltage and electrolysis time) on physical and chemical properties (pH, oxidation-reduction potential (ORP), total chlorine and free chlorine) of electrolyzed water (AcEW and AlEW) using Titanium-Stainless Steel 316 (cathode-anode) pairing were optimized by Response Surface Methodology (RSM). From RSM and Box-Behnken (BBD), optimal condition for AcEW is achieved at 0.8 wt% NaCl concentration, 11.52 V and 9.19 mins electrolysis time to produce optimum responses with pH of 2.96, 1216.237mV ORP and 16.27 mg/L free chlorine. Optimal condition for AlEW is achieved at 0.75 wt% NaCl concentration, 11.80 V and 9.56 mins electrolysis time in order to obtain the optimum values of responses with pH of 12.03 and -728.454mV ORP. The corrosion rates of the Titanium-Stainless Steel 316 (cathode-anode) were determined at ranges between (0.012 to 0.024 gcm-2h-1) for stainless steel 316 (anode) and (0.00-0.003 gcm-2h-1) for titanium electrode (cathode).

The result suggests that Titanium-Stainless Steel 316 are the best electrode pairing to produce electrolyzed water that is suitable as an alternative of green cleaner.

ABSTRAK

Tujuan projek ini adalah untuk menyiasat kesan bahan elektrod (Titanium-Stainless Steel 316, Stainless Steel 316-Nickel dan Stainless Steel 316-Aluminium Alloy) terhadap penjanaan air elektrolisis sebagai pembersih hijau untuk aplikasi industri makanan. Air elektrolisis adalah salah satu penyelesaian pembersihan dan pembersihan hijau terkini yang menawarkan penjimatan kos, menawarkan kemudahan yang lebih besar dalam mencari alternatif dan penyelesaian sanitasi yang mesra alam. Air elektrolisis asid (AcEW) mempunyai keberkesanan bakteria kuat pada banyak mikroorganisma. Sementara itu, air elektrolisis alkali (AlEW) berpotensi sebagai alternatif medium pembersih untuk pembersihan alkali. Beberapa pasangan elektrod digunakan semasa kajian elektrolisis. Hasilnya menunjukkan bahawa Titanium-Stainless Steel 316 adalah pasangan elektrod terbaik dalam menghasilkan air yang di elektrolisis. Pengaruh parameter elektrolisis (kepekatan NaCl, masa voltan dan elektrolisis) terhadap sifat fizikal dan kimia (pH, potensi pengurangan oksidasi (OPR) jumlah klorin dan klorin bebas) air elektrolisis (AcEW dan AlEW) menggunakan Titanium-Keluli Tahan Karat 316 (pasangan katod-anod) dioptimumkan dengan Metodologi Permukaan Respons (RSM). Dari RSM dan Box-Behnken (BBD), keadaan optimum untuk AcEW dicapai pada kepekatan NaCl 0.8 wt%, masa elektrolisis 11.52 V dan 9.19 min untuk menghasilkan tindak balas optimum dengan pH 2.96, 1216.237mV ORP dan klorin bebas 16.27 mg / L. Keadaan optimum untuk AlEW dicapai pada kepekatan NaCl 0,75% berat, masa elektrolisis 11,80 V dan 9,56 minit untuk mendapatkan nilai tindak balas optimum dengan pH 12,03 dan -728,454mV ORP. Kadar kakisan Titanium-Stainless Steel 316 (katod-anod) ditentukan pada julat antara (0,012 hingga 0,024 gcm-2h-1) untuk keluli tahan karat 316 (anod) dan (0,00-

0,003 gcm-2h-1) untuk titanium elektrod (katod). Hasilnya menunjukkan bahawa Titanium-Stainless Steel 316 adalah pasangan elektrod terbaik untuk menghasilkan air elektrolisis yang sesuai sebagai alternatif pembersih hijau.

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CHAPTER 1

INTRODUCTION

Severe outbreaks of foodborne pathogens and intoxications are the bigger threat for the food industries and consumers. Nowadays, food chains are becoming more difficult to handle, process, store, transport and maintain the safety of the food supply. Improper cleaning and sanitizing in food industry has been identified as a serious issue. Therefore, to ensure food safety, cleaning and sanitizing process should be optimized. There are so many commercial products available, but some of it has disadvantages such as can be toxic to human and environment, leftover of chemical residue and also overpriced. Electrolyzed water has been discovered as a novel sanitizer in Japan. Electrolyzed water becoming more popular due to it has the ability to be more efficient and cost effective than conventional cleaning agents. The major benefit of electrolyzed water for the inactivation of pathogenic microorganisms is it has less harmful effect on the environment and on the safety of consumers, because it has not consist of any dangerous chemicals.

1.1 History of Electrolyzed Water

Electrolyzed water has been widely used in various medical institutions in Japan since 1980, including water decontamination, water recovery and disinfection even though, the used of electrolyzed water was first introduced in Russia (Nikulin, 1977; Krivobok et al., 1982; Al-Haq et al., 2005; Hricova et al., 2008). Furthermore, the used of electrolyzed water has grown over time in numerous fields such as livestock management and agriculture (Al-Haq et., 2002; Buck et al., 2003; Stevenson et al., 2004).

According to (Shirahata et al., 2012), electrolyzed reduced water (ERW) was first developed in 1931, and implemented in 1954 and 1960 for usage in agriculture and medical treatment. In 1966, the Ministry of Education, Labor and Welfare, Japan declared ERW to be successful in treating chronic diarrhea, unusual gastrointestinal fermentation, indigestion, hyperacidity, and as an antacid. Moreover, the ministry has also approved ERW to be used as a home-use product.

Simplicity of development and implementation is the main reason for its acceptance. Electrolyzed water acceptability as a sanitizer is obvious from its use in a variety of fields including forestry, surgical sterilization, food hygiene, livestock control and other antimicrobial techniques (Kim et al., 2000; Huang et al., 2008).

1.2 Electrolyzed water as a green cleaner in food industry

Green cleaning and sanitizing actually create cost savings, offer greater convenience in finding alternatives, and reduce the use of harsh chemicals at the facility, which can give negative impacts to the environment and health. Hence, electrolyzed water is one of the latest green cleaning and sanitizing solutions available today.

Electrolyzed water is produced when salt solution pass through an electrolysis cell with two poles : anode (+) and cathode (-), with or without membrane (Huang et al., 2008; Cui et al., 2009). Membrane dividing systems can result in two types of water: anode-side acid electrolyzed water (AcEW) and cathode-side alkaline electrolyzed water (AlEW) (Huang et al., 2008; Cui et al., 2009). The main products at anode are Cl_2 dissolved, hipochlorous (HOCl) and hydrochloric acid (HCl) while at cathode sodium hydroxide (NaOH) and H_2 dissolved are produced. Water with sanitizer properties is produced at anode whereas at cathode produces water with cleaning properties due to Cl_2 (and HOCl) and NaOH respectively.

These two types of electrolyzed water are highly efficient, while both being environmentally friendly and safe for people. Electrolyzed water has safety benefits that make it suitable as cleaning and sanitizing device to use in high-risk environments such as hospitals, health care facilities and food processing environments. Moreover, electrolyzed water also has great utility for office, educational, entertainment, and hospitality applications.

In recent years, electrolyzed water (EW) has been considered as a new sanitizer (HOCl-containing Electrolyzed water) and cleaner (NaOH-containing Electrolyzed water). Electrolyzed water is produced without adding any harmful chemicals, except NaCl and regular water (Kim et al.,2000).

(Huang et al., 2008) observed that the use of EW is a sustainable and green concept. It has several advantages over conventionla cleaning systems including cost-effectiveness, ease of use, effective disinfection, on siteproduction and human and environmental safety. Jerome (2014) stated that electrolyzed water has been classified as a current and future food industry sanitizer and cleaner. U.S. authorities have approved the EW as a substitute for hazardous chemicals and as a green and safe alternative for household and industrial use. Moreover, EW has been used in various sectors in Russia and Japan for many decades, and it is slowly being recognized in the USA and elsewhere (Dickerson, 2009).

1.3 Sanitation in food industry

Rahman et al. (2016) stated that each year in the United States, 48 million people fall sick from foodborne diseases where 128,000 are hospitalized and 3,000 die. Norovirus, Salmonella, Clostridium perfringens, Campylobacter, and Staphylococcus aureus are the commonly bacteria that causes food poisoning. The best way to prevent foodborne disease is to ensure the food supply is secure. Therefore, it is important to clean and sanitize in order to produce high-quality, microbiologically safe food before it is introduced into the market.

Cleaning and disinfecting in the food industry is a critical part of the production cycle; if not properly handle, it can give serious consequences to food chain. Cleaning is the sequence of joint operations aimed at removing dirt from the surface of machinery or objects through the use of chemical and physical treatment whereas disinfectant is elimination of pathogenic microorganisms, viruses and bacteria in vegetative form by chemical or physical treatment (Sansebastiano et., n.d). The hygiene of food processing plants is known to be the key step to minimize food-borne infections and avoid economic loss.

Several techniques of disinfection have been studied and/or applied in the food chain. For instance, the used of hypochlorite, chlorine dioxide, hydrogen peroxide, hydrochloric acid, ozone, etc. as chemical disinfectant, physical treatments (heat and irradiation, etc.), and combinations of it (Koide et al.,2011; Zhang et al., 2011a, b). Yet, some of these methods have limitation when applied to minimally processed foods, including leftover chemical residues, poor inactivation effectiveness, adverse effects on human health or food safety, harm to the environment and expensive (Ramos et al., 2013; Al-Haq et al., 2005)

In addition, it has been stated by (Khalid et al., 2016) daily cleaning is mandatory in the food industry and mostly commercial cleaning chemicals used relatively are expensive. For instance, water, energy, chemicals, wastewater treatment and downtime costs are including in cleaning cost. Chemical cleaning can significantly affect the overall cost of cleaning. Thus, there is progressively demands on novel sanitation technologies for both food producers and customers to ensure the health, economical and freshness of minimally processed foods.

Table 1.1: Steps of cleaning and sanitizing system in food processing plant (Sansebastiano et., n.d)

No	Steps
1	Pre-washing to remove the gross dirt
2	Cleaning with water and detergents
3	Intermediate rinsing with water
4	Disinfection or sanitizing
5	Rinsing with water

According to the (Sansebastiano et., n.d), table above shows the steps of the cleaning and sanitizing system that used in food industry. It has been observed by (Holah., 2003) that cleaning with detergents can minimize the total microbial load. This reduction of the number of bacteria is beneficial for the subsequent disinfection process. Alkaline electrolyzed water can be used to replace the existing detergent such as sodium bicarbonate, sodium orthosulphate and sodium metasilicate where improper handling of this detergents can corrode metals and causes serious chemical burns if it comes into contact with skin. Whereas for disinfection or sanitizing, the most commonly disinfectants used in food industry are the peroxides (including hydrogen peroxide and peracetic acid) and the halogens (hypochlorous acid, chlorine dioxide and iodine) can be substitute by using acidic electrolyzed water as it contains sodium hypochlorite which can acts as an effective disinfectant.

1.4 Advantages of Electrolyzed Water

Electrolyzed water as a new cleaning and inactivation technology where is produced from salt and distilled water in an environmentally friendly process . It is a good substitute to chlorination and heat treatments, providing an alternative to from using harmful disinfectants. Electrolyzed water is not toxic to skin and mucous membranes, and it is very easy to handle, unlike other toxic disinfectants. It is also believed that electrolyzed water does not promote the growth of bacterial resistance (Hricova et al., 2008).

In addition, the use of electrolyzed water is comparatively cheap. The cost of use is incredibly low; the highest cost is the installation of an electrolyte unit, but only water, salt and electricity are required after the initial purchased (Huang et al., 2008). Moreover, Jeong et al. (2007) stated electrolyzed water has on-site manufacturing ability instead of modern cleaning and disinfecting agents are often ordered in bulk and distributed to plants where resulted in increasing of the transportation costs, demands for storage space, and the effort needed to reorder chemicals constantly. Hence, then usage of the electrolyzed water relatively can minimize the cost required.

The minimum environmental effects of EW is another significant aspect. In fact, electrolyzed water will disappears to its natural form and causes no harm to human health and the environment (Al-Haq et al., 2005). When the electrolyzed water is in contact with organic matter or undergo reverse osmosis with ordinary tap water, the water tends to form back to original state. Consequently, the effect on the environment is much less harmful compared to the use of chemical disinfectants, where the use of it is related to the transportation and storage of hazardous chemicals (Nakagawara et al., 1998; Tanaka et al., 1999).

1.5 Problem Statement

Currently, industry is undergoing changes where market leaders are focused primarily on producing processes and products that offer high-performance and economical. Beside that, environmental consciousness is well received by food producers. They are seeking for green cleaners with the same characteristics as industrial cleaning chemicals and at the same time give less environmental effect. In addition, demands for the use of green cleaning products are increasing in order to eliminate the production of non-biodegradable waste water and effluent.

Relatively, the food manufacturer are concerning of the consequences of the using industrial chemical during cleaning and sanitizing that may contaminate the food product and resulting in foodborne disease outbreaks where it can causes the loss and bad reputation to the food manufacturer. Hence, the proper and effective method for cleaning and sanitizing process are required in food industry in order to avoid any negative impacts.

Some food manufacturer tends to ignore the proper application of sanitation process due to the expensive cost are required for sanitation in food industry. Other than that, most of small and medium enterprise (SME) choose to use the cheaper cleaner and sanitizer as an alternative for economical sanitation cost. This substance may be harmful and toxic to human health and also to the environment. Hence, the inexpensive and economical cleaning cost are required in order ensure the food industry can implement the effective and safe cleaning and sanitizing process.

Many industries are not exposed to the usage of electrolyzed water as cleaner and sanitizer because the insufficient knowledge on electrolyzed water. Moreover, the soapy and good smell is one of the properties of the detergent that are being normalize in our society where it can give a good results in sanitation process. Hence, the awareness of the electrolyzed water as effective sanitation agent should be introduced to the industries.

Variables such as pH, ORP, salt concentration, type of electrode and others can be manipulated in order to have a good results of electrolyzed water. One of the variable that should be consider is type electrode where currently in industry, platinum electrodes are widely used due the properties of platinum that are high conductivity and resistance to corrosion. However, it is too expensive for small scale industry. Thus, the economical electrode that have almost similar properties as platinum should be choosed in order to minimize the cost. To have a good properties of electrolyzed water is the aim in this study where it can acts as efficient cleaner and sanitizer by manipulated and optimization of the variables.

1.6 Objective of the Study

The objectives of this project are:

i. To identify the best materials of electrode pairing (Titanium-Stainless Steel 316, Stainless Steel 316-Nickel and Stainless Steel 316-Aluminium Alloy) for electrolysis process based on physical and chemical properties (pH, oxidation reduction potential, free chlorine, total chlorine, dissolved oxygen and thermal conductivity) of acidic and alkaline electrolyzed water.

ii. To optimize the electrolysis parameter (NaCI concentration, voltage and electrolysis time) using the best materials of electrode pairing on physical and chemical properties (pH, oxidation reduction potential, free chlorine, total chlorine and dissolved oxygen, thermal conductivity) of acidic and alkaline electrolyzed water using Response Surface Methodology (RSM).

iii. To determine the corrosion rates of the best materials of electrode pairing.

1.7 Structure of thesis

This thesis are divided into five chapter. The following are specific description of every chapter.

Chapter 1 explains the background of the electrolyzed water. This chapter describe the acceptability of the electrolyzed water as green cleaner. Also, the cleaning process in food industry are briefly explained in thsi chapter following by the benefits of using electrolyzed water and objectives of this study.

Chapter 2 are based on the related and previous studies on application of the electrolyzed water as cleaner and antimicrobial agent. The electrochemistry of the production electrolyzed water are also explained in this chapter. The effect electrolyzing paramater on physical and chemical properties of electrolyzed water based on previous studies was discussed in this chapter. Following by effectiveness of the electrolyzed water, shelf life of electrode and corrosion rate of the materials according to related studies.

Chapter 3 explained the experimental procedures, materials and equipments used in conducting this study. The experimental design for this work is by production of the electrolyzed water, determination of the physical and chemical properties of electrolyzed water and its optimization.

Chapter 4 shows the results analysis obtained for optimization of the electrolyzed water by RSM. Presents the best materials of electrodes pairing choosen in this study and also the optimal condition of the electrolyzing paramter. The rates of corrosion obtained also being discussed in this chapter.

Chapter 5 concludes the study and some recommendation for future study in generating the electrolyzed water that high efficiency as sanitizer and cleaner are being made in this chapter.

CHAPTER 2

LITERATURE REVIEW

Based on the previous and related findings on the application of the electrolyzed water, it has been widely used as cleaner that are not harmful to the human and environment. The effectiveness of electrolyzed water as novel of sanitizing in food industry has been described in previous studies. The effects of electrolyzing parameter on physical and chemical properties are also briefly explained in this chapter. Roles of electrolyzed water as detergent and disinfectant is proved to be efficient according to the previous studies.

2.1 Electrolyzed water as a cleaner solution

As stated by Rahman et al. (2016) electrolyzed water can be used as a detergent (electrolyzed water with sodium hydroxide) and as a disinfectant (electrolyzed water with hypochloric acid). Disinfectants are used to clean the surface to make sure the surface is clear from pathogenic microbes. Detergents are mostly chemical compounds that are used on any surface to dissipate grease, eliminate dirt and soil. Electrolyzed water fulfills all of these properties and acts as an an efficient detergent and disinfectant that can be applied in the food industry and also other sectors that related to public health (Sansebastiano et al., 2007).

Electrolyzed water has been used in wide range of application such as application in agriculture, seafood and fish, hospital and food industry. During both pre-harvest and post-harvest production, such as storing, cleaning and washing of raw materials, in pipelines and utensils, as well as during packaging food safety and quality must be assured. Several researchers have studied on the efficacy of NEW or AEW and suggested both as novel food contact surface sanitizers (Izumi, 1999; Deza et al., 2005; Deza et al., 2007). Moreover, Lee et al. (2007) also stated that the use of AEW solution managed to reduce the bacterial population on metal and plastic surfaces and on reusable wipes of cloth.

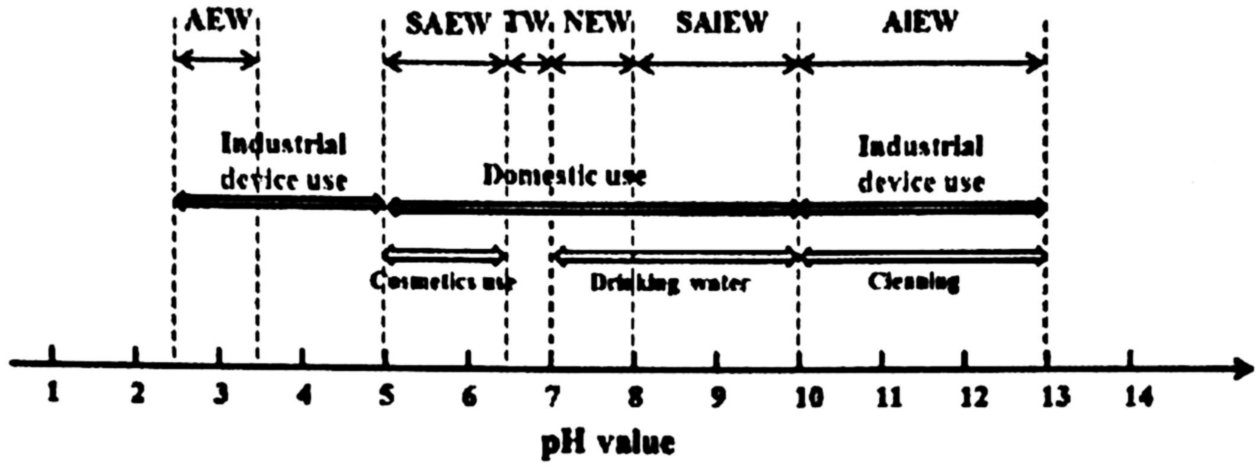


Figure 2.1: Various applications of electrolyzed water at different pH ranges (Xuan and Ling,2019)

As depicted in Figure 2.1 , it shows the application of the electrolyzed water at different ranges of pH. Acidic electrolyzed water with low pH range are suitable for industrial device use while alkaline electrolyzed water with high pH range are suitable for industrial device use.

In Japan's sushi industry, they saved millions of dollars by cleaning raw fish with electrolyzed water since electrolyzed water has already shown good results as a sanitizer for seafood and fish and its implementation is to avoid foodborne outbreaks (Rahman et al., 2016). In addition, Guentzelet al. (2011) recommended that AEW could be used as a sanitizing method to cultivate greenhouses, packing houses, facilities and industrial systems for the control or prevention of *Monilinia fructicola* and *B. cinerea* infections. Thus , the application EW as a cleaner has been applied in wide ranges of activity due to the properties electrolyzed water that can acts as good detergent and disinfectant.

2.2 Electrolyzed Water as an Antimicrobial Agent

In past few years, electrolyzed water has obtained an increasing interest as a new sanitizer. Several studies have shown the strong bactericidal efficacy of electrolyzed water on different type microorganisms including bacteria, molds, viruses, etc. (Afari and Hung, 2018b; Ding et al., 2016; Huang et al., 2008; Hricova et al., 2008; Rahman et al., 2016). The antimicrobial activity against numerous microorganisms such as *Escherichia coli, Listeria monocytogenes, Salmonella typhimurium, S. aureus,* and *Vibrio parahaemolyticus* has been recorded (Anonymous, 1997; Bari et al., 2003; Park et al., 2009; Issa-Zacharia et al., 2010; Quan et al., 2010; Zhang et al., 2011a, b; Sun et al., 2012).

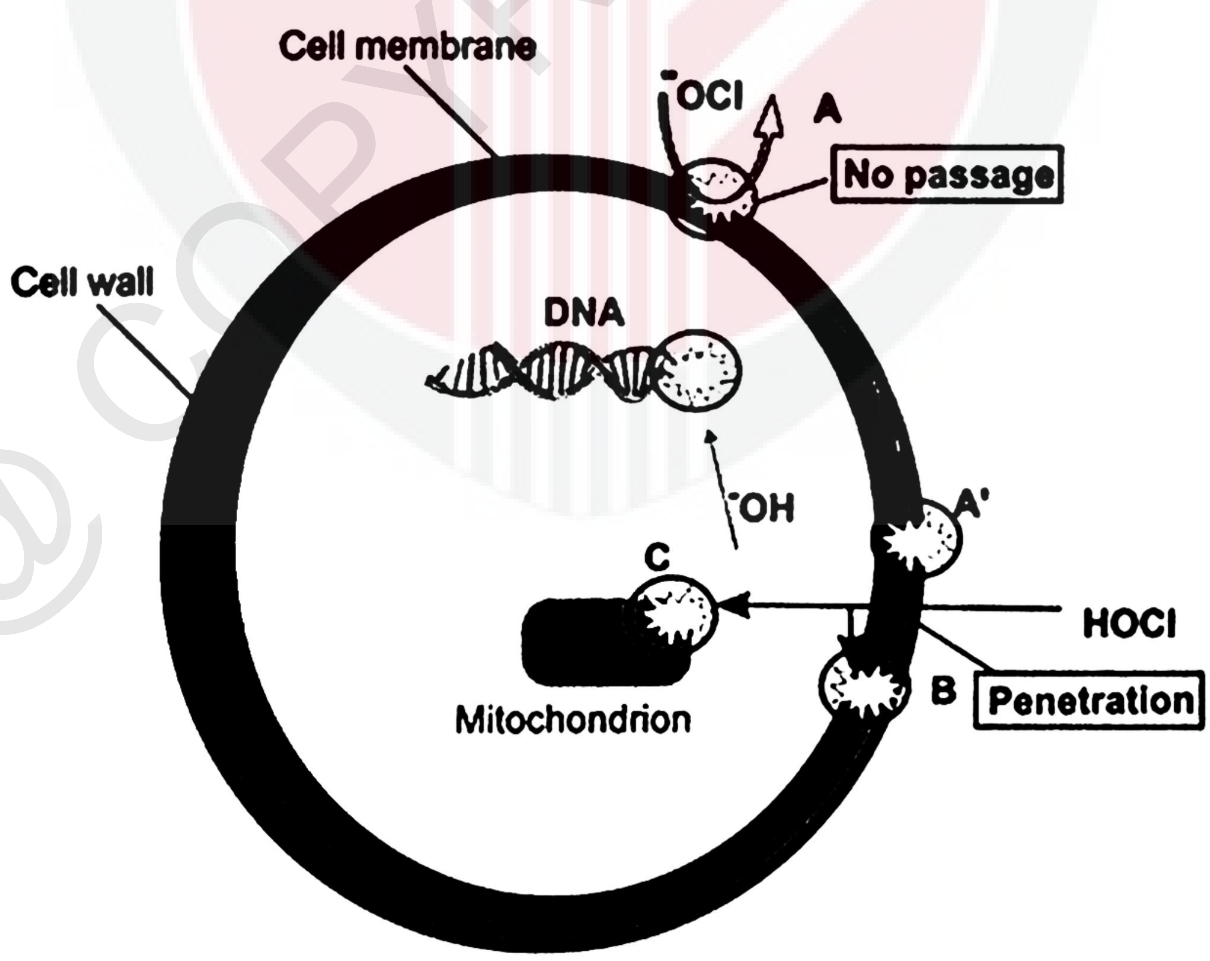


Figure 2.2 : Model of the EW germicidal activity

Fukuzaki (2006) constructed a model as shown in Figure 2 to illustrate sodium hypochlorite's germicidal action. Ionized –OCl has shown limited germicidal efficiency and cannot cross the microbial membrane. Ionized –OCl only targets outer cell of the membrane (circle A) due to the structures of the microbial cell wall that unable the penetration of the ionized -OCl. In the germicidal action, HOCl acts as an active component and has neutral charge which can pass through the membrane of the cell. HOCl will rupture the outer membrane (circle A) and the inner cell (circle B and C). It is assumed that the germicidal action of HOCl or −OCl is due to the inhibition of the enzyme activity necessary for microbial growth, disruption to the membrane also DNA, and apparently degradation in the ability of membrane transport.

The free chlorine species such as ClO-, Cl2, HClO, ClO2 in eletrolyzed water are completely responsible for their antimicrobial ability (Huang et al., 2008). It is well recognized that the active species of chlorine lead to microbial cells being inactivated. Throughout electrolysis, other oxidants such as reactive oxygen species (ozone and hydrogen peroxide) are formed, which also correspond to the antimicrobial capability of electrolyzed water (Jeong et al., 2007, 2009).

Microbial properties are main factors which influence the effectiveness of EW inactivation. Most studies have shown that Gram-positive bacteria are more resistant to EW than Gram-negative bacteria (Guentzel et al., 2008; Kim et al., 2000b; Park et al., 2004). Ovissipour et al. (2016) stated that AlEW could help penetration of active chlorine agents and disrupt the cell walls by destabilizing the extracellular polymeric compounds within the envelopes of bacterial cells. Furthermore, AlEW with extremely low ORP may disrupt the cell membranes, contributing to microbial death.

AEW has been identified to have a significant antimicrobial impact on various microbes for example, *L. monocytogenes,E. coli, B. cereus,* and *Salmonella* (Hao et al., 2017; Koseki et al., 2003; Ovissipour et al., 2016; Park et al., 2009a; Xiong et al., 2010). AEW values with low pH (< 2.7) and high ORP (> 1100 mV) are expected to cause inactivation of the microbes. Typically, microbial cells usually sustain under a pH of 4–9 (Gao et al., 2008). Thus, a low pH helps to degrade compounds in the cell wall (e.g., polysaccharides) and increase the permeability resulting in microbes death. The environmental protection and high antimicrobial activity are the main benefits of electrolyzed water to be applied as a sanitizer.

2.3 Electrochemistry of Electrolyzed Water

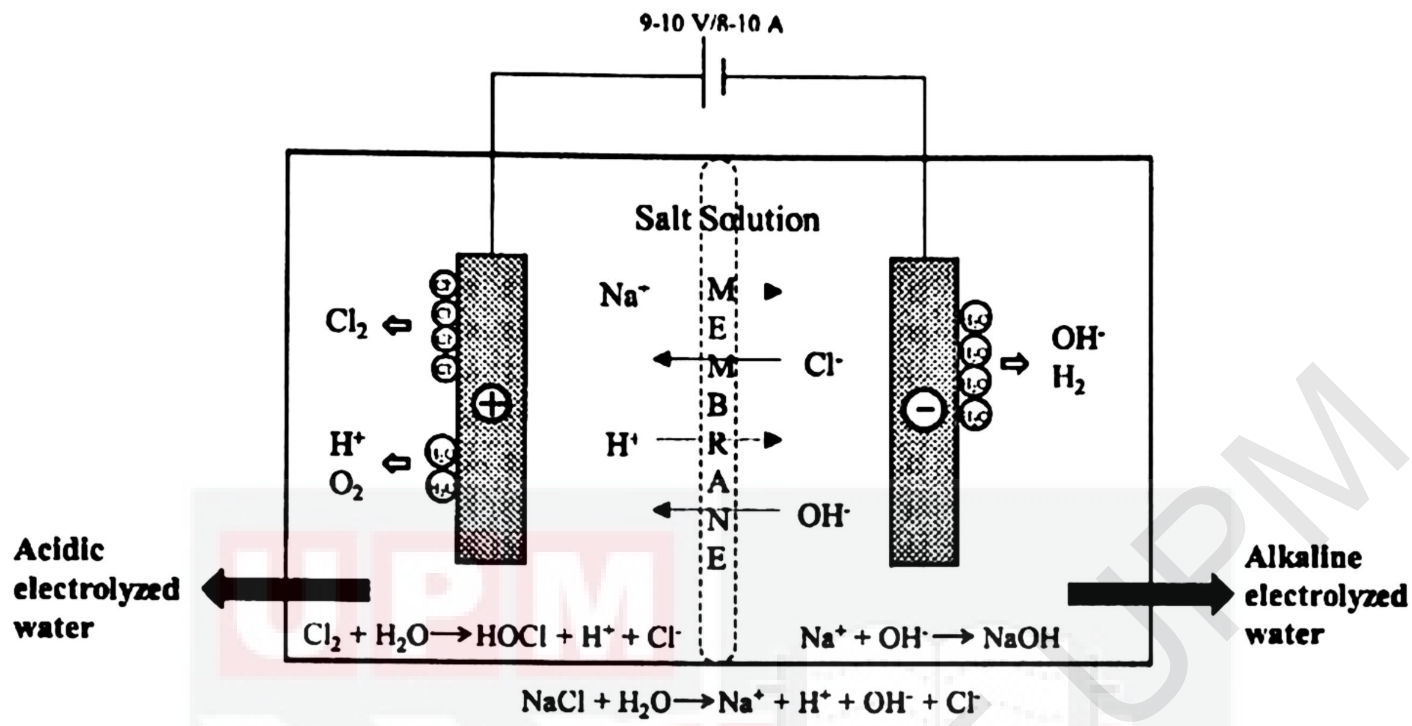


Figure 2.3 : Acid and alkaline electrolyzed water production schematics diagram (Al-Haq et al.2005)

Hricova et al.,(2008) described in their studies that production electrolyzed water is formed in a chamber of electrolysis containing a solution of dilute NaCl. The chamber has a diaphragm (membrane or septum) that divides the cathode from the anode. According to figure above, at the positive pole and the negative pole, different electrolyzed water solutions are obtained (Al-Haq et al. 2005).

Positively charged ions (hydrogen and sodium) moving into the cathode, attracting electrons, and then becoming hydrogen gas (H_2) and sodium hydroxide (NaOH). Based on positive pole reactions, low pH (2–3) acid electrolyzed water (AEW), high oxidation reduction potential (ORP, > 1000 mV), and obtainable chlorine concentration (ACC 10–90 ppm) are formed.

Whereas, negative ions (chloride and hydroxide) move to the anode where they lose electrons and then turn into oxygen gas (O_2), chlorine gas (Cl_2), hypochlorite ion ($-OCl$), hypochloric acid (HOCl), and hydrochloric acid (HCl). Based on the negative pole reactions, high pH (10–13) and low ORP (−800 to −900 mV) alkaline electrolyzed water (AlEW) is produced (Hsu, 2005; Hricova et al., 2008).

The generation theory of AEW and AlEW is shown in figure 2.3 with the following reactions:

At anode chamber (positive pole) :

Equation 21

$$2NaCl \rightarrow Cl_2 \uparrow + 2Na^+ + 2e^-$$

Equation 2.2

$$2H_2O \rightarrow O_2 \uparrow + 4H^+ + 4e^-$$

Equation 2.3

$$Cl_2 + H_2O \rightarrow HCl + HOCl$$

At cathode chamber (negative pole) :

Equation 2.4

$$2NaCl + 2OH^- \rightarrow 2NaOH + Cl^-$$

Equation 2.5

$$2H_2O + 2e^- \rightarrow 2OH^- + H_2 \uparrow$$

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

There are many factors that affect the physical and chemical properties of electrolyzed water and responsible for efficiency of electroyzed water include current, electrolyte, concentration of NaCl, type of electrode, storage conditions and temperature (Hsu et al., 2016; Rahman et al., 2016).

2.4.1 Salt concentration, Amperage, Voltage and Electrolysis Time

Rahman et al. (2012) & Hsu (2003) stated that current , water flow rate, and salt/acid concentration can influenced the basic characteristics of the EW. Other than that, voltage, output and flow rate settings parameters also can have a significant impact on the pH and ORP of alkaline electrolyzed water (Sharma & Demirci 2003). The effects of current flow on EW sanitizing efficacy against foodborne pathogens has been demonstrated by Rahman et al. (2012a). They observed a log reduction of 4.9-5.6 CFU / mL for both *E. coli O157:H7* and *L. monocytogenes* when the current increased from 1.15 A to 1.45 A. Thus, it shows with an increasing in the current value, the values of ORP, ACC and pH also increased.

Park et al. (2004) generated acidic electrolyzed water with a pH of 2.57, 1082 mV of ORP and about 50 mg / L of free chlorine at 14 A setting. Show that, high amperage and voltage contribute to a more acidic solution with a high ORP and a free concentration of chlorine. Acidic electrolyzed water successfully prevents the growth of bacteria due to low pH, high ORP, and the presence of HOCl. Besides that, Brychcy et al. (2015b) investigated the impact of EW on yeast and mold and the effect on pork muscle of psychrotrophs. When spraying the pork muscle with 0.1 percent NaCl electrolyzed for 10 min (pH 2.2, ORP 1159 mV, ACC 16.6 mg / L), the largest reductions in yeast and mold and psychrotrophs were reported. This findings showed that more effective decontamination can benefit from the use of more concentrated salt solution and longer electrolysis time in the generation of EW.

According to Al-Haq et al. (2002 &2005), the amount of NaCl added and the amount of HOCl produced during the electrolysis process are linearly associated. Furthermore, it was reported by Hsu (2005) that salinity was associated linearly with conductivity where increasing the salt concentration resulted in high electrolyzed water conductivity in the feeding solution.

Next, an increasing water flow rate has been found to produce a higher electrical current because a larger quantity of salt solution is electrolyzed per unit time, where electrolyzed water with low ACC and ORP are produced (Hsu, 2003 & 2005). Moreover, it has been shown that the salt concentration and electrolysis time have favorable correlates with the free chlorine concentration, which could be clarified by the fact that the electrolysis effectiveness of the electrolysis cell and the separation efficacy of the ion exchange membrane are significantly reduced with increased flow rate and salt concentration (Kiura et al., 2002).

2.4.2 Type of Electrodes

The formation of such strong oxidants can be effected by various reaction parameters, including current or voltage, temperature, pH, electrolyte composition, electrode material and method of electrolysis. Among these, the most significant parameter is the electrode material that determines the production of oxidants and other bacteria (Martinez-Huitle & Brillas, 2008). Generally, in electrochemical experiments that use platinum electrode as the anode, there is an increase in pH due to an increase in NaCl concentration, which improves SAEW production at a suitable level of pH (Quan et al., 2010; Rahman et al., 2012a; Forghani et al., 2015). The cost of platinum electrode is relatively expensive. Hence, Symes et al. (2015) suggested in using Stainless steel 316 and nickel electrode as it have good conductivity and economical cost. It also suggested by (Bewer, 2013) to use titanium electrode because it has great extent for electrochemical process equipment and for electrodes.

Jeong et al. (2009) also discovered that electrode material selection plays a major role in oxidant development. In addition, it was observed that the sequence of electrode materials ordered for active chlorine processing was as follows: Ti / IrO_2 > Ti / RuO_2 > Ti / Pt–IrO_2 > BDD > Pt. They also observed that reactive oxygen species like OH^-, O_3, and H_2O_2 were effected by the type of material that used as the anode.

2.4.3 Galvanic series for electrode materials selection

According to (Baboian & Shahida, 2016) galvanic corrosion is very likely occurs when two or more different metals are connected electrically,with the more active one operating as anode and will corrodes, while the less active one is cathode. The active metal is the metal with more negative potential in the electromotive force series of metals; while the noble metal is the metal with less negative potential (Ettefagh et al., 2017). It is also being observed by (Popov, 2015) that the metal with more positive potential will protected cathodically by the metal with more negative potential thus there will be less corrosion occurs at cathode. The potential difference between two metals in contact,produces electron flow through a conductive medium. As the driving force is the potential difference.This type of corrosion is called galvanic corrosion.

Alloy		*Voltage Range of Alloy vs. Reference Electrode**
Magnesium	Anodic or Active End	-1.60 to -1.63
Zinc		-0.98 to -1.03
Aluminum Alloys		-0.70 to -0.90
Cadmium		-0.70 to -0.76
Cast Irons		-0.60 to -0.72
Steel		-0.60 to -0.70
Aluminum Bronze		-0.30 to -0.40
Red Brass, Yellow Brass, Naval Brass		-0.30 to -0.40
Copper		-0.28 to -0.36
Lead-Tin Solder (50/50)		-0.26 to -0.35
Admiralty Brass		-0.25 to -0.34
Manganese Bronze		-0.25 to -0.33
Silicon Bronze		-0.24 to -0.27
400 Series Stainless Steels**		-0.20 to -0.35
90-10 Copper-Nickel		-0.21 to -0.28
Lead		-0.19 to -0.25
70-30 Copper-Nickel		-0.13 to -0.22
17-4 PH Stainless Steel †		-0.10 to -0.20
Silver		-0.09 to -0.14
Monel		-0.04 to -0.14
300 Series Stainless Steels ** †		-0.00 to -0.15
Titanium and Titanium Alloys †		+0.06 to -0.05
Inconel 625 †		+0.10 to -0.04
Hastelloy C-276 †		+0.10 to -0.04
Platinum †	Cathodic or Noble End	+0.25 to +0.18
Graphite		+0.30 to +0.20

* These numbers refer to a Saturated Calomel Electrode.

** In low-velocity or poorly aerated water, or inside crevices, these alloys may start to corrode and exhibit potentials near -0.5 V.

† When covered with slime films of marine bacteria, these alloys may exhibit potentials from +0.3 to +0.4 V.

Figure 2.4 : Galvanic series in flowing seawater (Dexter,1999)

Dexter, (1999) also stated that when a galvanic pair formed, the anode is one of the metals in the pair that corrodes quicker than it does on its own, whilst the other is the cathode and corrodes slower than it would alone. Figure above shows the the galvanic seawater series is a list of ranked metals and alloys according to their ability to corrode in marine environments. When the two metals from the list are coupled together, the closer one to the (or active) end of the series, in this case the upper end, will be the anode and easily corrodes, while the one at the cathodic (or noble) end will corrode slower. This voltage difference, will drives the current flow to accelerate anodic metal corrosion

There are two main factors influencing the occurrence of galvanic corrosion are the difference in voltage between the two metals on the galvanic series, and the size of the cathodic metal exposed area relative to the anodic metal. Anodic metal corrosion is both faster and more destructive as the difference in voltage increases, and as the cathode area increases compared to the anode area.

In the galvanic series also, when metal attached to a metal which is more cathodic to it, the metal seems to corrode. The further apart the metals or alloys are in the series, the faster the more anodic (baser) metal can corrodes. Galvanic corrosion may not occur when two metals, such as copper and brass, are joined near each other in the galvanic series. Metals close to each other create minimal corrosion risk (Ahmad, 2006).

2.5 Effectiveness of Electrolyzed Water

Ironically, when AEW was used for 5 min with 43 ppm of ACC, the spores and vegetative cells showed over 6 orders of magnitude reduction. *Aspergillus parasiticus spores* with an initial count of 1000 were denatured when treated with AEW containing 20 to 30 ppm of active chlorine 15 min (Suzuki et al., 2002; Vorobjeva et sl., 2004). Exposure to AEW, *Bacillus cereus spores* was reduced by 3.5 orders of magnitude for 2 min, while vegetative cells were reduced by 8.0 log CFU / mL in 0.5 min (Kim et al., 2000a).

Guentzel et al. (2008) stated the efficacy of AEW treatment on spinach and lettuce with ACC 100–120 ppm at pH 6.3 and exposure time is 10 min against *S.typhimurium, E. coli, L. monocytogenes, S. aureus,* and *Enterococcus faecalis.ssp*. There is 1-to-3 log reduction of *E. coli O104:H4, L. monocytogenes, Campylobacter jejuni, Aeromonas hydrophila,* and *Vibrio parahaemolyticus* in suspension by alkali electrolyzed water (Ovissipour et al., 2016). Kim et al. (2000a) stated that , *E. coli O157:H7* and *L. monocytogenes* is fully denatured were observed with AEW treatment of 56 ppm ACC at 24 ° C for 30 s.

Foodborne disease associated with pathogens found in fruits and vegetables has frequently appeared around the world in recent years. *L.monocytogenes, Salmonella spp.* and *shigatoxin-producing Escherichia coli* had been found in fruits yet vegetables as three major pathogens (Silva et al., 2017; Vojkovska et al., 2017). Important steps should be taken during the processing and storage of fruits and vegetables, such as arranging, grading ,cleaning, peeling, cutting and shredding, increasing opportunities for food safety hazards like microbial contamination, pesticide residues, moth invasion and etc (Bempah et al., 2016; Castro-Ibáñez et al., 2017; Rady et al., 2017). However, it is well known that AEW has demonstrated its strong bactericidal impact on various fruit and vegetable micro-organisms including *Escherichia coli* (Graça et al., 2011; Hao et al., 2006, 2015a; Pangloli and Hung, 2013), *Listeria innocua* (Graça et al., 2009, 2011), *Salmonella choleraesuis* (Graça et al. 2011), *Salmonella typhimurium* (Ding et al., 2011; Park et al., 2009), *Salmonella enteric* (Fishburn et al., 2012), *Cronobacter sakazakii* (Santo et al., 2016), *Bacillus cereus* (Ding et al., 2011; Ju et al., 2017), *Bacillus subtilis* (Hao et al., 2011a, b), and *Pseudomonas fluorescens* (Ignat et al., 2016).

The latest USDA legislation has encouraged and improved the use of post-lethal and/or antimicrobial or surface treatments to promote safety and reduce the risk of pathogenic bacteria during RTE meat products processing (USDA-FSIS, 2014). The use of EW to decontaminate animal-derived foods like fresh red meat, ready-to-eat beef, poultry and shell eggs has been effective in reducing pathogenic microorganisms such as *C. jejuni, E. coli O157:H7, Salmonella spp., S. aureus,* and *L.monocytogenes.*

It was examined by Veasey and Muriana (2016) the EW antimicrobial activity with various pH values (4, 5 & 6) against *E. Coli* on fresh beef O157:H7 and *L.Monocytogenes* for 30 s on ready-to-eat beef (Frankfurters). Almost no change was observed during diagnosis, compared to that observed in the monitor. Moreover, AEW or AlEW have similar effectiveness of antimicrobial activity on *L.Monocytogenes* inoculated on RTE meats including frankfurters and ham (Fabrizio and Cutter,2005).

Aquatic resources that include fish shrimps, crabs and shellfish are high-quality sources of dietary protein and these proteins can also meet additional requirements amino acids for human. Pathogenic or spoilage bacteria are likely to contaminate aquatic products during the manufacturing, distribution and selling process. This bacteria affect the quality of seafood, shorten the shelf life and even pose a potential risk to human health. Even so, electrolyzed water (EW) acts as a novel sanitizer, has been commonly used in many countrie's seafood industries, including the USA, China, Japan and so on. Through preventing pathogenic or spoilage bacteria in fish, EW has proven to improve the safety of seafood products. Recent research suggests that this innovative technique could effectively remove the bacterial biofilm that this bacteria produced (Han et al., 2017).

Qi et al. (2018) studied the efficacy of electrolyzed water in the oxidation and elimination of three residues of pesticides on fresh produce. This investigated the impact of pH, ACC, and AEW and AlEW treatment time on the degradation of diazinon, cyprodinil, and phosmet in aqueous solution and on fresh produce. This is because residues and pesticide accumulations pose a potential threat to human health and cause environmental damage. The ACC, pH, and ORP are the three main factors make EW ,water an effective antimicrobial reagent and directly related to the elimination of pesticides.(Huang et al., 2008). Hence, according to previous studies it shows that electrolyzed water as an effective solution that has been applied in wide application due to the all potential mechanism of electrolyzed water in order to avoid foodborne outbreaks and diseases.

2.6 Shelf life of electrolyzed water

Various types of EW displayed different storage characteristics. For example, NEW has been observed more stable over the storage period than AEW (Nagamatsu et al., 2002; Cui et al., 2009). Hsu & Kao (2004) confirmed that the AEW properties such as ORP, electrical conductivity and pH did not change significantly, whereas the dissolved oxygen (DO) and ACC content decreased significantly during storage of the EW. Rahman et al. (2016) stated that chlorine evaporation over time and atmospheric exposure will reduce the efficacy of AcEW and NEW. In addition, it was observed by (Len et al., 2002) that chlorine loss in EW under open conditions was due to chlorine evaporation along with atmospheric exposure will reduce the efficacy of electrolyzed water.

According to (Hsu & Kao, 2004) the major inactivation part (HOCl) is lost by increasing solution temperature and storage time, thereby it will reduce the EW inactivation operation. It is suggested that a relatively lower solution temperature and closed storage may improve EW storage shelf life. Moreover, the lower storage temperature (4 ° C) made these basic EW properties more stable than those stored at 25 ° C and preserved their bactericidal performance for 12 months (Nagamatsu et al., 2002; Fabrizio and Cutter, 2003; Robinson et al., 2012).

Electrolyzed water physiochemical properties show dramatic change over time, both under closed and open conditions (Len and others 2002; Rahman and others 2012a). In this study, it was also shown that LcEW (Low concentration electrolyzed water) bactericidal activity against cell suspension of *E. O157:H7 coli* and *L.monocytogenes* under open conditions were sustained up to 6 d and 14 d under closed storage conditions (Rahman and others 2012a). From previous study, electrolyzed water efficacy has decreased after 24 hours of storage. Thus, EW that produced using the lab-scale electrolyzing unit, it is recommended for immediate use after production to minimize the changes in properties due to time and atmospheric exposure (Khalid et al., 2018).

2.7 Corrosion Rates of Materials

Corrosion is extremely damaging and can develops in any environment, including atmosphere, air and water mixture, industrial atmosphere. Other than that, fresh, saline water, organic and inorganic solutions or media also can causes the corrosion occurs (Samina et al., 2011; Abdulmaruf and Dajab, 2007; Kumar et al., 2013; Ikpesu, 2014). In addition, Kumar et al. (2013) & Ikpesu (2014) stated that corrosion happens gradually or rapidly and the rate at which it happens can be measured using various methods and the most popular technique is weight loss technique.

The splitting of water into hydrogen and oxygen (electrolysis process) requires a material with good current (conductivity) and high corrosion resistance. Stainless Steel (S.S) alloy provides superior electrolysis process behavior. Additionally, stainless Steel (S.S.) 410 has outstanding corrosion resistance compared to other types of stainless steel, this is because it contains large quantities of nickel where nickel plays a crucial role in assessing the corrosion potential of stainless steel (Nassar & Nassar, 2016). Eyu et al. (2016) observed that the inner corrosion in mild steel pipelines in a high bicarbonate or chloride system can be reduced if the dissolved oxygen concentration at (pH $\geq$8) and maximum ORP (−600 mVSCE) is relatively low (Eyu et al.,2016).

Alar et al. (2013) explained that the good characteristics of corrosion resistance were found in material with the highest percentage of chromium, molybdenum, and nickel. Materials with a high percentage of chromium and iron and a relatively low proportion of molybdenum and nickel displayed a high level of corrosion protection at (22±2) ° C, whereas this protection not adequate at (50±2) □. Other than that, carbon steel, copper and aluminum also respectively had a decent, strong, good and excellent resistance to corrosion in electrolyzed water (Ayebah & Hung,, 2015).

There is method suggested by (Bewer, 2013) that the degradation of the electrodes materials can be reduce with polishing of the metal after the process, where it will remove the oxide layer due to exposure to salt solution hence it will increase the electrochemical performance of the electrodes.

2.8 Summary

Electrolyzed water has demonstrates antimicrobial activity against a range of microorganisms and removes the most severe forms of viruses, bacteria, fungi and spores in relatively short period in food items, food processing surfaces and non-food surfaces. The good properties of the electrolyzed water make it suitable to substitute the commonly chemical used in cleaning of food industry. Electrolyzing parameter such as salt solution concentration, voltage, electrolysis time and type of electrode are studied. There are several findings related to the production and application of the electrolyzed water and this chapter briefly explained the better understanding of the application of the electrolyzed water.

CHAPTER 3

METHODOLOGY

For this study, the optimum condition of acidic electrolyzed and alkali electrolyzed water using the best electrode pairing based on physical and chemical properties which is pH, oxidation reduction potential, free chlorine, total chlorine, dissolved oxygen and thermal conductivity was obtained by manipulating certain parameter such as NaCI concentration (0.05-1.0 wt %), electric voltage (5-15V), electrolysis time (5-10mins) and type of electrodes. The corrosion rate of the electrodes also being determined by using weight loss of the electrode after being immersed in the electrolyzed water.

3.1 Experimental Set-Up

This experiment began firstly with producing the NaCI solution with different concentration (0.05-1.0 wt %) to produce different type of electrolyzed water which is acidic and alkali electrolyzed water. The salt solution is pour into electrolyzing unit that separated by the membrane to produce electrolyzed water in different chamber anode and cathode. Different pairing of electrodes is place inside the ioniser at different chamber anode and cathode.In order to start the electrolysis process the DC power supply is connected with different voltage supply (5-15V). Ion exchanged process occurs after the power is supply with varies of electrolysis time (5-15mins) to produce the acidic electrolyzed water (AcEW) and alkali electrolyzed water (AlEW) at different chamber that are separated by the membrane. As soon as the electrolysis process stop , the acidic electrolyzed water (AcEW) and alkali electrolyzed water (AlEW) are collected at different chamber.

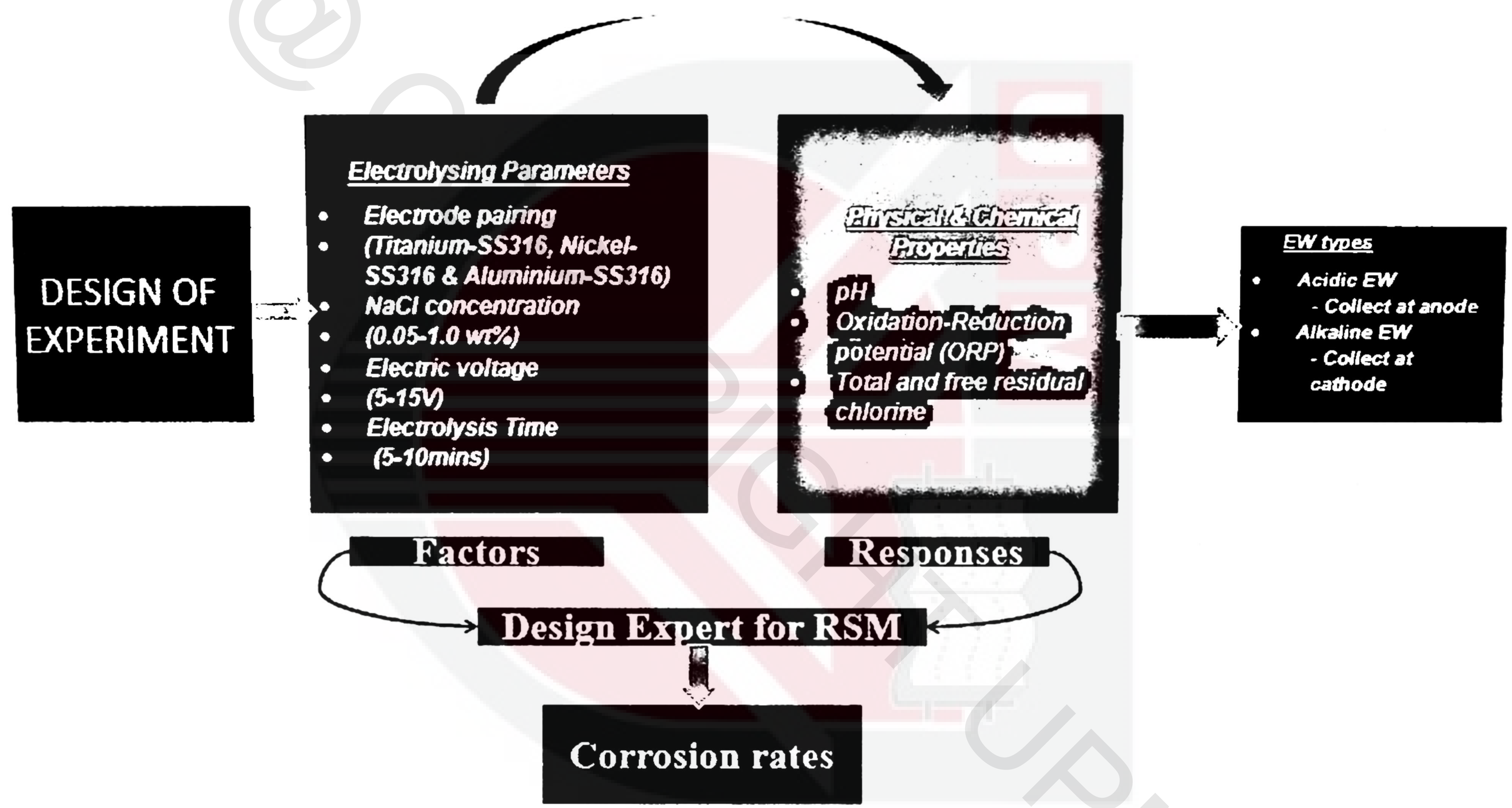


Figure 3.1 : Flow Chart Summary of the Experiment

3.2 Materials and Chemical

3.2.1 Electrodes type

The electrodes that used in this experiment are choose based on its properties of electrical conductivity, corrosiveness and current efficiency. The pairing of the electrodes are based on the galvanic series. The noble metal in the pairing is set at cathode while the active metal is set at anode.

In order to study the efficiency on the physical and chemical properties of electrolyzed water, different type of electrodes are used in this study. Titanium-Stainless Steel 316 , Stainless steel 316-Nickel and Stainless steel 316-Aluminium alloy are set (cathode-anode) from Good Fellow Cambridge Limited, Huntingdon, England. The size of each electrode is 10 x 10 cm.

3.2.2 Chemical used

Different concentration of NaCI solution is prepared by using Sodium Chloride (NaCI) Grade AR, from Friendman Schmidt Chemical. The concentration of the salt solution was determined by using this formula ,

Equation 3.1

$$\frac{x(g)}{3400(ml)} x100\% = \%ofNaCI$$

3.2.3 Type of solvent used

Solvent that used to dissolve the sodium chloride (NaCI) are distilled water. Distilled water are used to produce salt solution with different range of concentration (0.05-1.0 wt%).

3.3 Type of instrument used

3.3.1 pH reading measurement

The instrument used to measure pH reading of the electrolyzed water is pH/mV/ISE meter with pH electrode from Fisher Scientific, USA. The pH reading of the alkali and acidic electrolyzed water is measured before and also after the electrolysis process by immersing the pH probe into the electrolyzed water. The reading of the pH is recorded for both chambers.

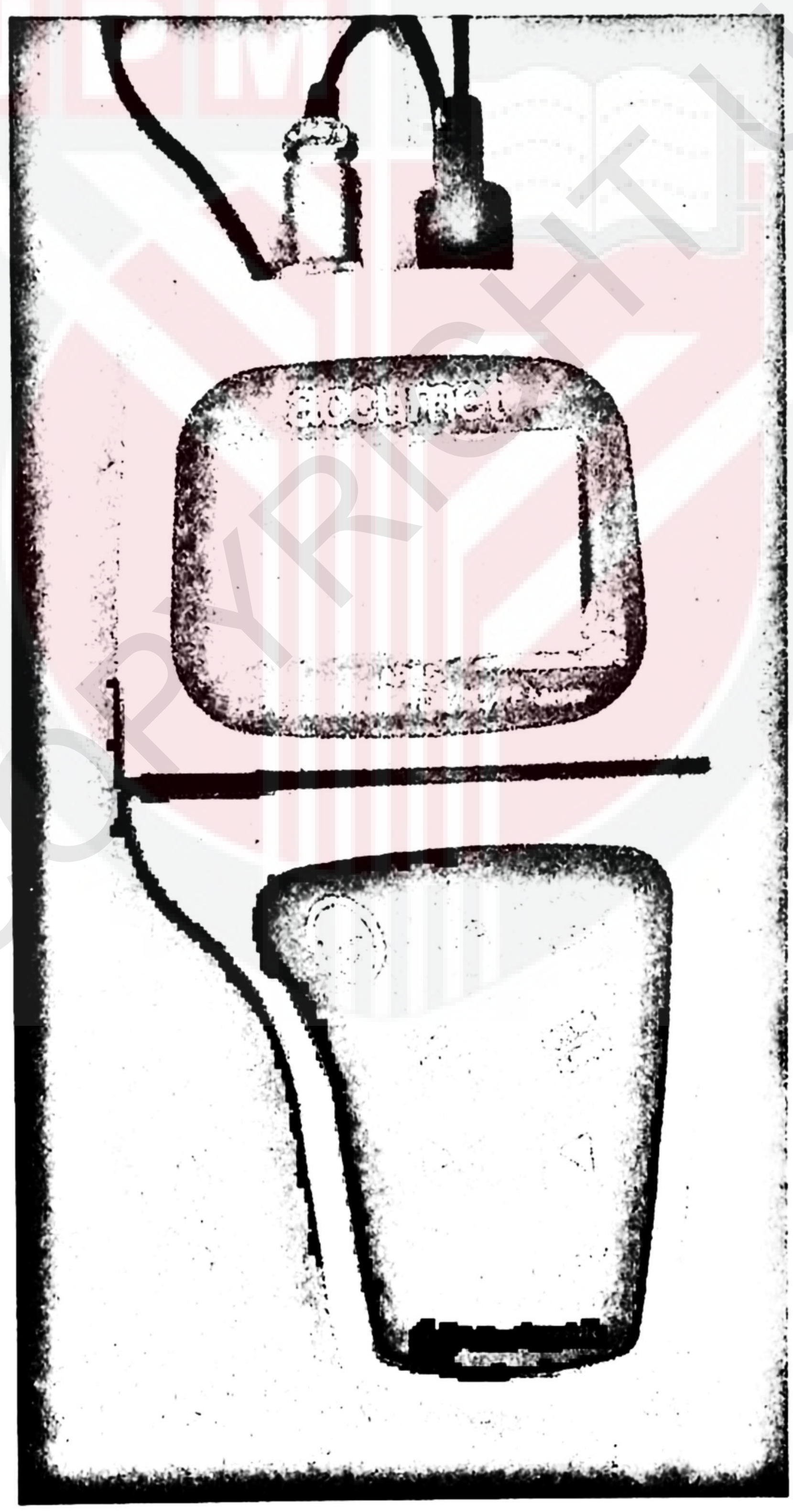


Figure 3.2 : AP85 Portable Waterproof pH/conductivity meter

3.3.2 Lab-Scale Electrolyzing Unit

The instrument used to produce electrolyzed water for this experiment is lab scale electrolyzing unit which was fabricated in Universiti Putra Malaysia. Figure 3.2 shows the configuration of the instrument used for this experiment. The lab scale electrolyzing unit is used in this experiment due to the parameters such as voltage, NaCI concentration , electrolysis time and electrode can be manipulated according to the requirement instead of the conventional electrolyzed water generator.

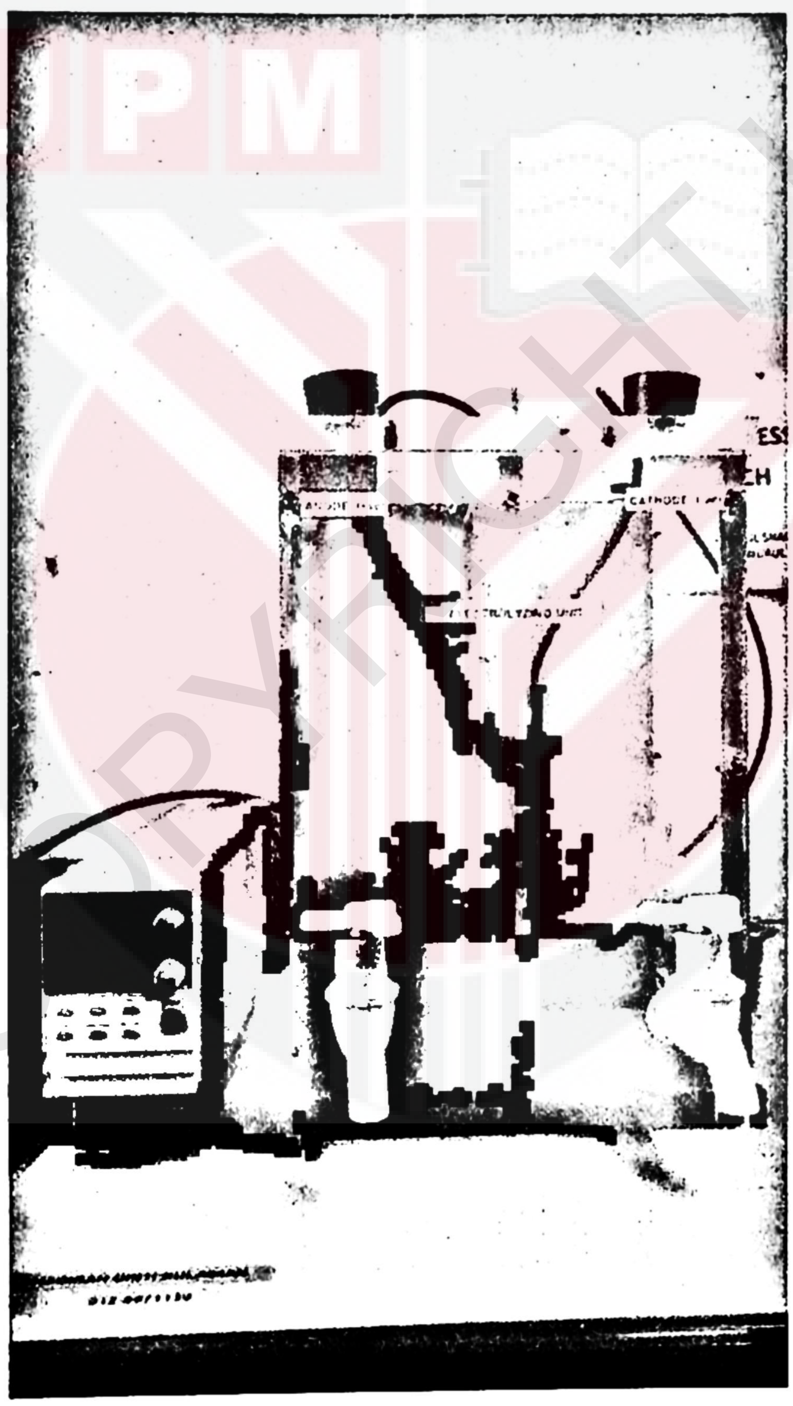


Figure 3.3 : Lab- Scale Electrolyzing Unit

3.3.3 Oxidation - Reduction Potential (ORP) reading measurement

The ORP which is knowns as oxidation-reduction potential is measured by using pH/mV/ISE meter equipped with redox electrode from Boeco, Germany in unit millivolts. The reading of ORP is taken initially before the electrolysis process start, the ORP reading also is taken after the electrolysis process by immersing the probe into the electrolyzed water and the value of ORP taken is recorded.

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

3.3.4 Total and free chlorine reading measurement

The instrument used to measure the total and free chlorine value is Photometer from Macherey-Nagel, Germany. The reading is taken before and after electrolysis process start.

After the electrolysis process, the reading of total chlorine and free chlorine are taken separately. 5ml of acidic electrolyzed water was pipette inside the closed tube and one sachet of CI_2-1 powder is added, then shake the sample well for 20 seconds. After that placed the closed tube inside the chlorine meter to measure the reading of the total chlorine. Also the same procedure are repeated to measure the reading of the free chlorine.

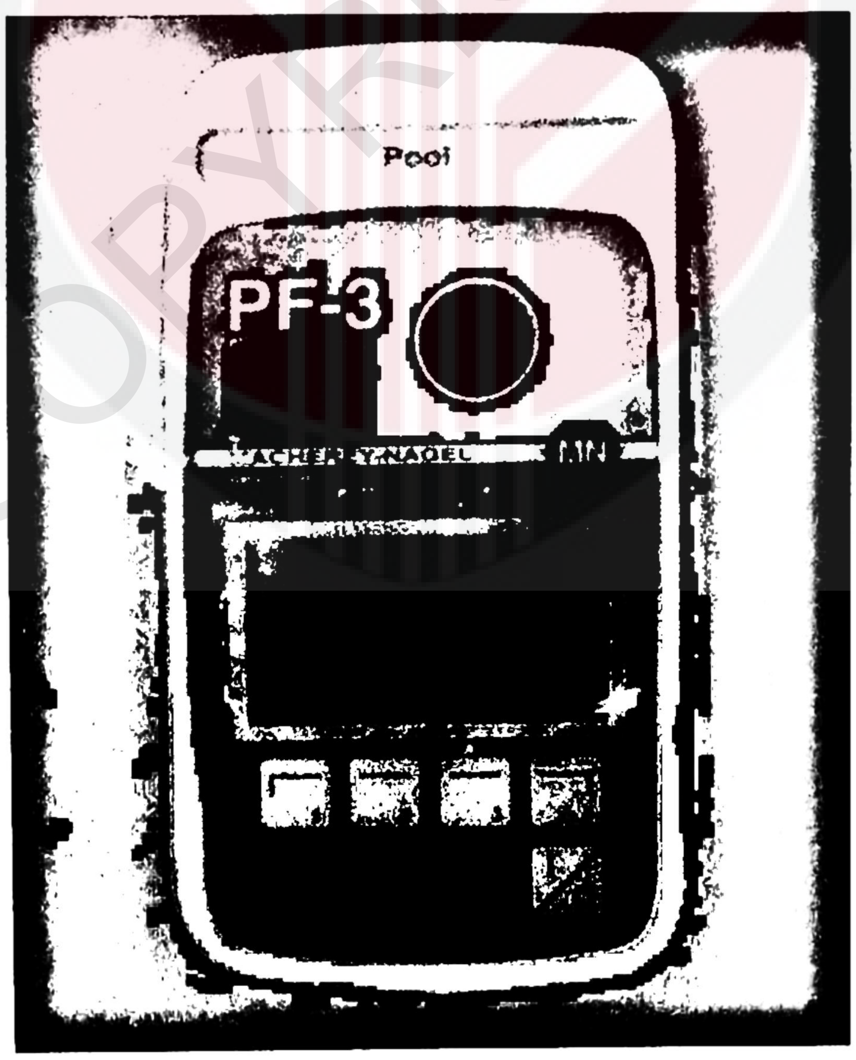


Figure 3.5 : Photometer PF-3 Macherey Nagel

3.3.5 Dissolved oxygen reading measurement

The reading value of the dissolved oxygen (DO) is taken before and also after the electrolysis process by using oxygen meter from Hanna Instruments, USA. The probe is immersed inside the electrolyzed water to measure the value of the dissolved oxygen of acidic electrolyzed water (AcEW) and alkali electrolyzed water (AlEW).

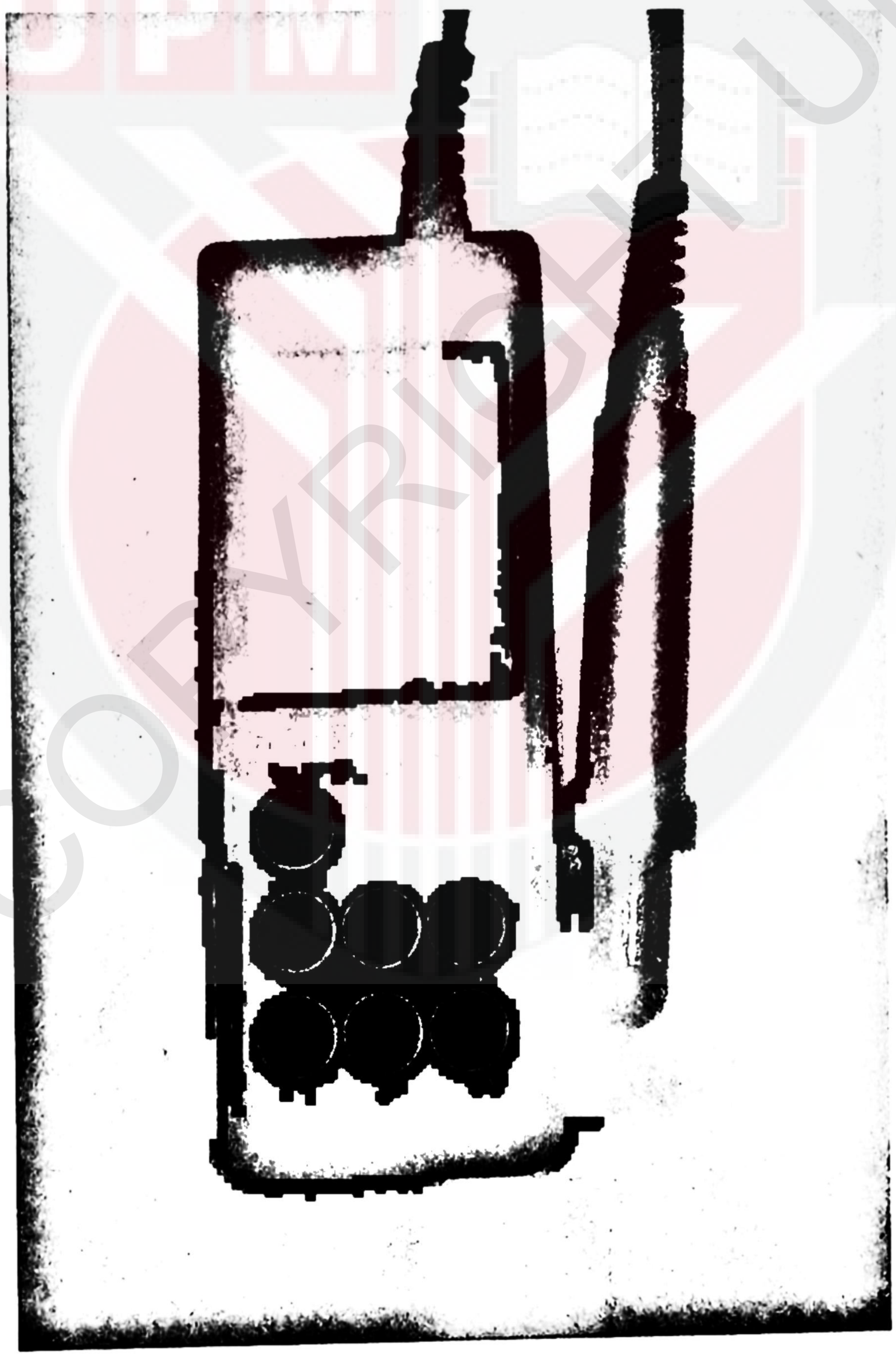


Figure 3.6 : HI 9147 Dissolved Oxygen Meter

3.3.6 Thermal conductivity reading measurement

Reading of thermal conductivity of the electrolyzed water is measured by using SD 70 Conductivity Meter from LabFriend, Australia. The reading for thermal conductivity of electrolyzed water is taken before conducting electrolysis process and also after the electrolysis process. The probe of instrument is immersed inside the electrolyzed water to measure the reading of thermal conductivity.

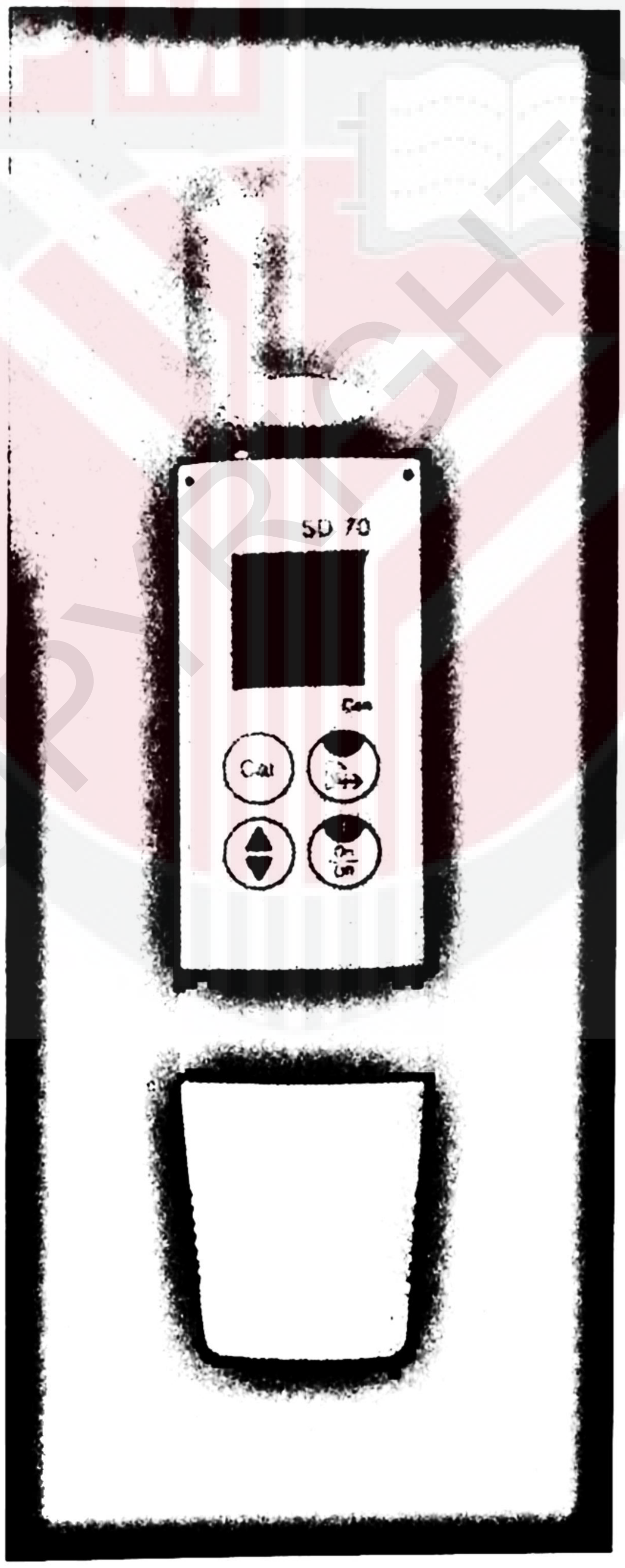


Figure 3.7 : SD 70 Conductivity Meter

3.4 Current efficiency of electrode materials

According to Faraday's law, current efficiency is the ratio of the actual mass of subtance liberated from an electrolyte by the current's passage to the theoratical liberated, theoratical total chlorine were calculated using equation (3.2) to (3.4) (Khalid et al., 2018). The experimental mass chlorine produced was calculated using equation (3.5). Using equation (3.6) & (3.7) were used to calculate current density and current efficiency.

Charge transferred, Q (A/s) = *Electric current, I (A) x Electrolysis time, t (s)*

Equation 3.2

$$\text{Number of mol electron transferred, n (mol)} = \frac{\textit{Charge transferred, Q (A/s)}}{\textit{Faraday constant, F (C/mol)}}$$

Equation 3.3

Theoretical mass of chlorine produced, m (g) = *n (mol) x Molar mass (g/mol)*

Equation 3.4

Experimental mass of chlorine produced, m(g) = *Experimental chlorine produced (mg/L) x volume of water used for electrolysis (L)*

Equation 3.5

$$\text{Current density, J (A/m2)} = \frac{\textit{Electrical current (A)}}{\textit{Effective surface area of anode, A, } (m^2)}$$

Equation 3.6

$$\text{Current efficiency (\%)} = \frac{\textit{Experimental production of total chlorine (mg)}}{\textit{Theoratical production of total chlorine, (mg)}} x100\%$$

Equation 3.7

3.5 Response Surface Methodology (RSM)

Design method used for optimization of the electrolysis process by using response surface methodology (RSM). RSM is a commonly used mathematical and statistical tool for modeling and evaluating a mechanism in which different variables influence the response of interest (Braimah, Anozie, & Odejobi, 2016). Where the dependent variable is factors that influencing the method, while responding variable is the responses of the process (Koc, & Kaymak-Ertekin, 2010). In this experimental design the dependent variable is the electrolysing parameters which is type of electrodes, electrolysis time, NaCI concentration and voltage while the responding variable is physical and chemical properties of the electrolyzed water such as pH, ORP, total chlorine and free chlorine, dissolved oxygen, thermal conductivity. RSM also examines the correct relationship between input and output variables and determines the ideal operating conditions for a system under analysis or a factor field area that meets the operating requirements (Farooq, 2013). According to the Koc & Kaymak-Ertekin, 2010 two primary experimental designs that used in RSM are Box-Behnken designs (BBD) and central composite design (CCD) where this will be used in optimization of the electrolyzed water.

3.6 Corrosion rate of the electrodes

The corrosion rate of the electrode is using the best pairing electrodes that resulted in optimum condition of acidic and alkali electrolyzed water. The method in determining the corrosion rate of the electrode is using weight loss method. Weight loss method is one of the most commonly used approaches to estimate metal corrosion losses. It is simple and straightforward, requiring no theoretical assumptions or approximations and applicable to all corrosive conditions, regardless of the type of corrosion that occurs (Hung et al., 2005).

The initial weight of the electrodes is taken before start the electrolysis process. After the electrolysis process, the electrode was cleaned using acetone solution to remove grease and oil. Next, rinsed the electrode with distilled water and cleaned again the electrode using ethanol solution to remove any contaminants. The electrode was rinsed again using distilled water and placed inside the dessicator for 24 hours. Lastly, the final weight of the electrode is recorded. Rates of corrosion was calculated using this formula,

Equation 3.8

$$Rc = \frac{\Delta w}{At}$$

Δw = Weight difference (final weight - initial weight) (g)

A = Surface area of electrode (cm^2)

t = Immersed time (h)

3.7 Summary

The experimental method for this study are divided into three main part. The first part is the acidic electrolyzed water (AcEW) and alkali electrolyzed water (AlEW) are produced using lab scale electrolyzing unit with different manipulated parameters (NaCI concentration, Electrolysis time, Voltage and type of electrodes) to obtain result for pH, ORP, free chlorine, and total chlorine. Secondly, Response Surface Methodology and Box-Behnken Design are used to obtain optimum condition of the electrolyzed water by optimization of the results that obtained from lab work which is pH, ORP, free chlorine and total chlorine value. Lastly, the corrosion rate of electrodes are determined by using weight loss method. The best pairing of the electrodes with optimum condition of electrolyzed water that are obtained from optimization of electrolyzed water is used.

CHAPTER 4

RESULTS AND DISCUSSION

The results analysis on effect of different electrolyzing parameter (NaCl concentration, electrolysis time, electrode type & voltage) on the physico-chemical properties (pH, Oxidation-Reduction Potential & Chlorine content) of Acidic electrolyzed water (AcEW) and Alkaline electrolyzed water (AlEW) are discussed in this chapter. Relatively, AcEW can acts as the disinfenctant where it is effective in cleaning the surface from pathogenic microbes. Meanwhile, AlEW can acts as detergent, where it will eliminate physical contamination on the food contact surface. The effects of electrolysis parameter (NaCl, electrolysis time, voltage) was evaluated by using Response Surface Methodology (RSM) to obtain the optimum condition of electrolyzed water that can be use in sanitation and cleaning process on food contact surface in food industry. The optimum condition of electrolyzed water was obtained from the results of RSM in order to produce electrolyzed water that have high effectiveness on cleaning and sanitize the food contact surface. The expected results from RSM and empirical data was compared in this study. The validation of optimization of electrolyzed water with experimental results are compared and also discussed in this chapter.

4.1 Selection anode and cathode materials

4.1.1 Current efficiency of the electrode materials

According to the Table 4.1 it shows electrical potential, current, theoretical production of total chlorine, experimental production of total chlorine, current density and current efficiency of the different electrode materials at 10 minutes and 0.53 wt% of NaCl concentration. It is important to know the current efficiency of the materials in order to know the effectiveness of the electrolysis process in producing chlorine which is one of properties of electrolyzed water that ensure the microorganism is eliminated during sanitation and cleaning process. Hsu et al. 2015 stated that when the current efficiency is increasing, the chlorine concentration will also increase.

Table 4.1 : Current efficiency for different electrodes pairing at 0.53 wt% NaCl concentration and 10 mins electrolysis time

Voltage (V)	**Current (A)**	**Theoretical production of total chlorine, (mg/L)**	**Experimental chlorine produced (mg/L)**	**Current density, (A/m^2)**	**Current efficiency (%)**
		Titanium - SS316 pairing			
5	0.43	27.88	4.32	43	15.5
15	2.37	153.68	11.90	237	7.7
		SS316 - Nickel pairing			
5	0.58	37.61	0.30	58	0.8
15	1.80	116.72	0.70	180	0.6
		SS316 - Aluminium Alloy pairing			
5	0.75	48.63	0.84	75	1.7
15	2.91	188.69	0.19	291	0.1

Titanium- SS316 material has the best percentage of current efficiency which at 5V it shows 15.5% of efficiency compared to the SS316-Nickel and SS316-Aluminium alloy at 5V only show 0.8% and 1.7% of current efficiency. In addition, Titanium-SS316 pairing have highest value of experimental total chlorine production which is 4.32mg/L when conducting electrolysis process at 5V, 0.53 wt% within 10 minutes incomparable to the another electrode materials which only produced 0.3mg/L and 0.84mg/L of experimental total chlorine. Another electrode materials such as SS316-Nickel and SS316-Aluminium alloy have low current efficiency might due to the corrosion during electrolysis process where the corrosion causes the amount of chlorine production is low. The precipitate formed from the corrosion of the electrode materials resulting in low current efficiency (Hsu et al., 2015).

Hence, Titanium-SS316 appears as a good electrode material that have higher current efficiency and also total chlorine production either theoretical or experimental when electrolysis process is carried out at 5V, 0.53 wt% for 10 mins where it will increase the effectiveness of the electrolyzed water as antimicrobial agent.

4.1.2 Physico-chemical properties changes at both chambers

The good criteria of AcEW should have high antimicrobial activity has a low pH value, high ORP value and high chlorine content. Contrary to the AlEW criteria, should have high pH value , low ORP value and usually does not contain chlorine. Bacteria can grow optimally at pH of 4 to 9. Moreover, the aerobic and anaerobic bacteria can grow in liquid at ORP value range of 200mV to 800mV and -700mV to 200mV (Huang et al., 2013). The outer membrane of bacteria is ruptured at low pH and HOCl contain in AcEW penetrates into cell (McPherson, 1993). Meanwhile, NaOH contain in the AlEW is a broad septrum for cleaning solution. In this work, three different pairing of electrodes are used to produce electrolyzed water at different chamber. The AcEW is produced at anode chamber while AlEW is produced at cathode chamber.

According to Table 4.2, it shows the physico-chemical properties changes of AcEW and AlEW that are produced by using different type of electrodes material pairing. Titanium as cathode electrode is paired with Stainless steel 316 as anode electrode (Titanium-SS316) gives the best results on the physico-chemical propertiesof AcEW and AlEW produced. Meanwhile, the pairing of SS316 (cathode) / Nickel(anode) and SS316(cathode)/ Aluminium alloy (anode) shows the poor characteristic on AcEW but moderate and good on AlEW characteristic. Both of this electrodes material pairing might be suitable in only producing AlEW application.

Corrosion resulting the effectiveness of both EW either AcEW or AlEW are reduced. Hence, several factor such as the position of the electrode material in galvanic series should be taken into account in order to avoid the galvanic corrosion occurs which may affected the electrolysis process. Ahmad (2016), explained that galvanic corrosion may not occur when the metal are joined near to each other in galvanic series. It can be shown that less corrosion is occured when titanium is pairing with SS316, this is because the position of both electrode material are near to each other in the galvanic series.

Table 4.2 : Physico-chemical properties of AcEW and AlEW produced with different electrodes materials pairing

[redacted]	[redacted]	[redacted]
[redacted]	***GOOD***	***GOOD***
[redacted]	***POOR***	***MODERATE***
[redacted]	***POOR***	***GOOD***

Thus, Titanium-Stainless steel 316 pairing are choosen out of three electrodes pairing as the capability of this pair on producing AcEW and AlEW that have high effectiveness on cleaning and sanitation process. Variety effect Titanium-SS316 on the physico-chemical properties of the electrolyzed water are discussed in this study.

4.2 Effects of NaCl concentration on the physico-chemical properties of electrolyzed water

According to Rahman et al (2012) & Hsu (2003) NaCl concentration is one of the factor that can influenced the basic characteristc of the electrolyzed water. Thus, physico-chemical properties of electrolyzed water are relatively affected by the amount of NaCl added. In this work, the NaCl concentration 0.05wt% (1.7g), 0.053wt% (18.02g) and 1.00wt% (34g) are used. The salt is diluted with distilled water to produce the respective concentration. The total volume of the electrolytes is 3.4L (1.7L in each chamber). Table 4.3 & 4.4 shows the effect of NaCl concetration on AcEW and AlEW for Titanium-SS316 pairing.

Criteria of the good AcEW should have low pH, high ORP and high chlorine content to ensure the AcEW as an effective sanitizer in decontaminated the microbial on the food contact surface. It is proved by Brychcy et al (2015b) that AcEW (pH of 2.2, 1159mV, ACC 16.6mg/L) was produced during electrolysis of 0.1wt% at 10 minutes can reduced the yeast and mold on pork muscle. From Table 4.3, increasing NaCI concentration from 0.05wt% to 1.00wt% resulting in increasing ORP value and chlorine content at the same time the pH value is lowered. At 0.53wt% and 1.00wt% for 10mins eletrolysis the value of pH and ORP are slightly similar except the chlorine content. Hence, it shows that the larger amount of the NaCl added, will produce AcEW with high chlorine content.

AlEW with high effieciency should have high pH value and low ORP value (negative value). Normally, the AlEW does not containing chlorine. Based on the Table 4.4, it shows that the 0.53wt% and 1.00wt% gives that best results on physcico-chemical properties of AlEW, whereas at 0.05wt% has no significant effect on AlEW. Therefore, the pH is increased and ORP value is lowered as the NaCl concentration increased.

Table 4.3 : Effect of NaCl concentration on physico-chemical properties of AcEW

NaCl (wt%)	pH	ORP (mV)	Free chlorine (mg/L)	Total chlorine (mg/L)
		10 mins		
0.05	4.18	530	0.14	0.18
0.53	2.99	1158	11.55	11.89
1.00	3.01	1166	23.40	23.85

Table 4.4 : Effect of NaCl concentration on physico-chemical properties of AlEW

NaCl (wt%)	pH	ORP (mV)
	10 mins	
0.05	9.27	228
0.53	11.86	-690
1.00	11.64	-712

4.3 Effect of electrolysis time on physico-chemical properties

Electrolysis time have the most significant effect on production of chlorine in AcEW after electrolysis proess is carried out for a certain time interval. Different electrolysis time are used in this study. Huang et al (2008) observed that longer electrolysis time will enhance the production of chlorine. Table 4.5, shows the genaration of chlorine for AcEW within 5mins and 10mins of electrolysis.

At 15V and 0.5wt% NaCl concentration, increases the electrolysis time from 5mins to 10mins resulting in increasing of the chlorine content. At 5 minutes of electrolysis process produce 3.83mg/L of free chlorine and 3.98 mg/L ot total chlorine respectively. Meanwhile, at 10 minutes, 23.42mg/L of free chlorine and 23.85mg/L of total chlorine is produced. As the for the AlEW, usually there is no chlorine content available, thus it tends to be ignored.

Table 4.5 : Free chlorine and total chlorine content for AcEW at 5 mins and 10 mins

NaCl (wt%)	Voltage (V)	Free chlorine (mg/L)	Total chlorine (mg/L)
		5 mins	
0.05	10	0.11	0.18
0.53	15	1.14	1.18
1.00	10	3.83	3.98
		10 mins	
0.05	10	0.14	0.18
0.53	15	11.55	11.93
1.00	10	23.40	23.85

4.4 Effect voltage on physico-chemical properties

As the electric potential increase, the higher the amount of electric current passes through the system. Where the electric current can influences basic characteristic of electrolyzed water (Rahman et al., 2015; Hsu, 2003). The NaCl concentration also rely on the amount of the elctric current. This study are conducted at 5V, 10V and 15V using Titanium-SS316 pairing. The results of the effect of voltage on the physico-chemical properties on EW are shown in table below.

For AcEW, the electrolysis is carried out for 10minutes at 15V, 0.53wt% give the best results on the physico-chemical properties where the pH and ORP is 3.0 and 1158mV . Unfortunantely, the chlorine that generate is lower than the chlorine produced at 15V, 1.00wt% within 7.5mins of electrolysis. For 0.53wt% the chlorine content is 11.6mg/L of free chlorine and 11.89 mg/L of total chlorine respectively while for 1.00wt% the chlorine content is 15.6mg/L and 19.28mg/L respectively. Experimentally, the trends from table 4.6 shows as the voltage increases, the pH, ORP and chlorine content also increases.

Based on the Table 4.7, the higher the voltage will resulting in lower pH and ORP value. Where at 10mins, 5V and 0.53wt% produce AlEW with pH of 11.86 and -690mV ORP value. Therefore, the voltage has significant effect on AlEW (Shawn & Demirci, 2003).

Table 4.6 : pH, ORP and Chlorine content of AceW at 5V and 15V

Voltage (V)	NaCl (wt%)	pH	ORP (mV)	Free chlorine (mg/L)	Total chlorine (mg/L)
			5 mins		
5	0.53	5.6	359	0.3	0.38
15	0.53	4.3	927	1.1	1.18
			7.5 mins		
5	0.05	5.6	448	0.1	0.15
15	0.05	3.7	863	0.9	10.1
5	1.00	3.8	1097	6.2	0.99
15	1.00	3.6	1134	15.6	19.25
			10 mins		
5	0.53	4.2	1018	2.2	2.41
15	0.53	3.0	1158	11.6	11.89

Table 4.7 : pH, ORP and Chlorine content of AlEW at 5V and 15V

Voltage (V)	NaCl (wt%)	pH	ORP (mV)
		5 mins	
5	0.53	10.16	128
15	0.53	11.19	-63
		7.5 mins	
5	0.05	6.48	456
15	0.05	10.90	199
5	1.00	11.19	-95
15	1.00	11.62	-130
		10 mins	
5	0.53	10.99	16
15	0.53	11.86	-690

4.5 Response Surface Methodology for Optimization usage of Electrolyzed Water

The effects of 3 independent variables of (NaCl, Voltage, Electroysis Time) on the 4 responses of physico-chemical properties (pH, Oxidation Reduction Potential, free chlorine & Total chlorine) for different type of electrode (Titanium, Nickel, Aluminium alloy and stainless steel) was evaluated by applying RSM and Box-Behnken design (BBD).

According to the preliminary data, BBD had three levels (-1, 0, 1) where it demonstrate NaCl concentration (0.05%, 0.53% & 1.0%), voltage (5V, 10V &15V) and electrolysis time (5mins, 7.5mins & 10mins). In order to obtain the highest free chlorine content, the desirability function was selected to optimize the process variable that involved. 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 is set. All the data were analyzed using Design-Expert 11.0 program software by Statease, Inc. Minneapolis, MN, USA by analysis of variance (ANOVA).

Each goal is set as follow for optimization process where for AcEW, the value of pH should be minimize while ORP and free chlorine content value should be maximize. In contrast, for AlEW the pH value should be maximize while ORP and free chlorine content value should be minimize. The combination of all these 3 factors are responsible in produce optimum condition of electrolyzed water. Table 4.10 and 4.11 are summarised of the goals for each response.

4.5.1 Development and analysis of the mathematical models

For development of mathematical models, the Box-Behken design was analysed using Design Expert software. Multiple linear regression analyses of the experimental data yielded second order polynomials models in predicting pH and ORP for both AcEW and AlEW. On other hand, analyses data yielded 2FI model in predicting pH for AcEW. Since the Titanium-SS316 has the higher production of free chlorine and total chlorine content among of the electrodes, thus the results of Titanium-SS316 was selected out of three types of pairing electrode materials.

For AcEW :

pH : $3.48 - 0.5750A - 0.5187B - 0.5813C + 0.4025AB + 0.0075AC - 0.0200BC + 0.4410A^2 + 0.2535B^2 + 0.3535C^2$ **(Equation 1)**

ORP : $1069.20 + 145.00A + 266.50B + 154.00C + 94.50AB - 107.00AC + 15.00BC - 40.35A^2 - 143.35B^2 - 163.38C^2$ **(Equation 2)**

Free Chlorine : $6.11 + 2.55A + 5.97B + 4.00C + 2.15AB + 2.12AC + 4.88BC$

(Equation 3)

For AlEW :

pH : $11.53 + 0.8675A + 1.59B + 0.6163C - 0.9500AB - 0.0400AC - 0.6875BC - 0.0408A^2 - 1.49B^2 - 0.4432C^2$ **(Equation 4)**

ORP : $-476.20 - 148.62A - 288.63B - 174.25C + 55.50AB - 128.75AC - 112.75BC + 254.85A^2 + 328.85B^2 + 69.10C^2$ **(Equation 5)**

Where A represents the coded NaCl concentration from -1 to 1 : B represents the coded electrolysis time from -1 to 1:and C represents the coded voltage from -1 to 1.

Table 4.8 : ANNOVA results of Model, Lack of fit and R^2 for AcEW and AlEW of Titanium-SS316

Responses	AcEW			AlEW		
	Model	Lack of Fit	R^2	Model	Lack of Fit	R^2
pH	significant	not significant	0.9793	significant	not significant	0.9418
ORP	significant	not significant	0.9462	significant	not significant	0.9079
Chlorine	significant	not significant	0.9036	/	/	/

Table 4.9 : ANNOVA results of factors for AcEW and AlEW of Titanium-SS316

Responses	AcEW			AlEW		
	Voltage	NaCl Conc	Electrolysis TIme	Voltage	NaCl Conc	Electrolysis TIme
pH	< 0.0001	< 0.0001	< 0.0001	0.0061	0.0002	0.0284
ORP	0.0042	0.0001	0.0031	0.044	0.0021	0.0238
Chlorine	0.0169	< 0.0001	0.0012	/	/	/

Based on the table 4.8, it shows the ANNOVA results of responses using Titanium-SS316 for both AcEW and AlEW. Correspondently, to indicate that model term are significant the p- value should less than 0.05. Furthermore, non- significant lack of fit is good where it is indicating the adequacy of all the models as the desired for model to fit. Regression coefficients (R^2) value should be >0.8 will indicate the model is reliable predicted the responses under tested condition in predicting experimental results. Table 4.9 shows that all the responses are significantly affected by the factors. Hence, it shows that by using Titanium-SS316 as electrode material, both of AcEW and AlEW resulting in a good model fit on predicting the responses. Practically, the mathematical model was analyzed by ANNOVA.

Table 4.10 : Criteria and limit of the numerical optimization of the responses of the Titanium-SS316 AcEW

Responses	**Goal**	**Lower Limit**	**Upper Limit**	**Lower Weight**	**Upper Weight**
pH	minimize	2	3	1	1
ORP (mV)	maximize	800	1200	1	1
Free Chlorine Content (mg/L)	maximize	0	90	1	1

Table 4.11 : Criteria and limit of the numerical optimization of the responses of the Titanium-SS316 AlEW

Responses	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight
pH	maximize	11	12	1	1
ORP (mV)	minimize	-900	-700	1	1

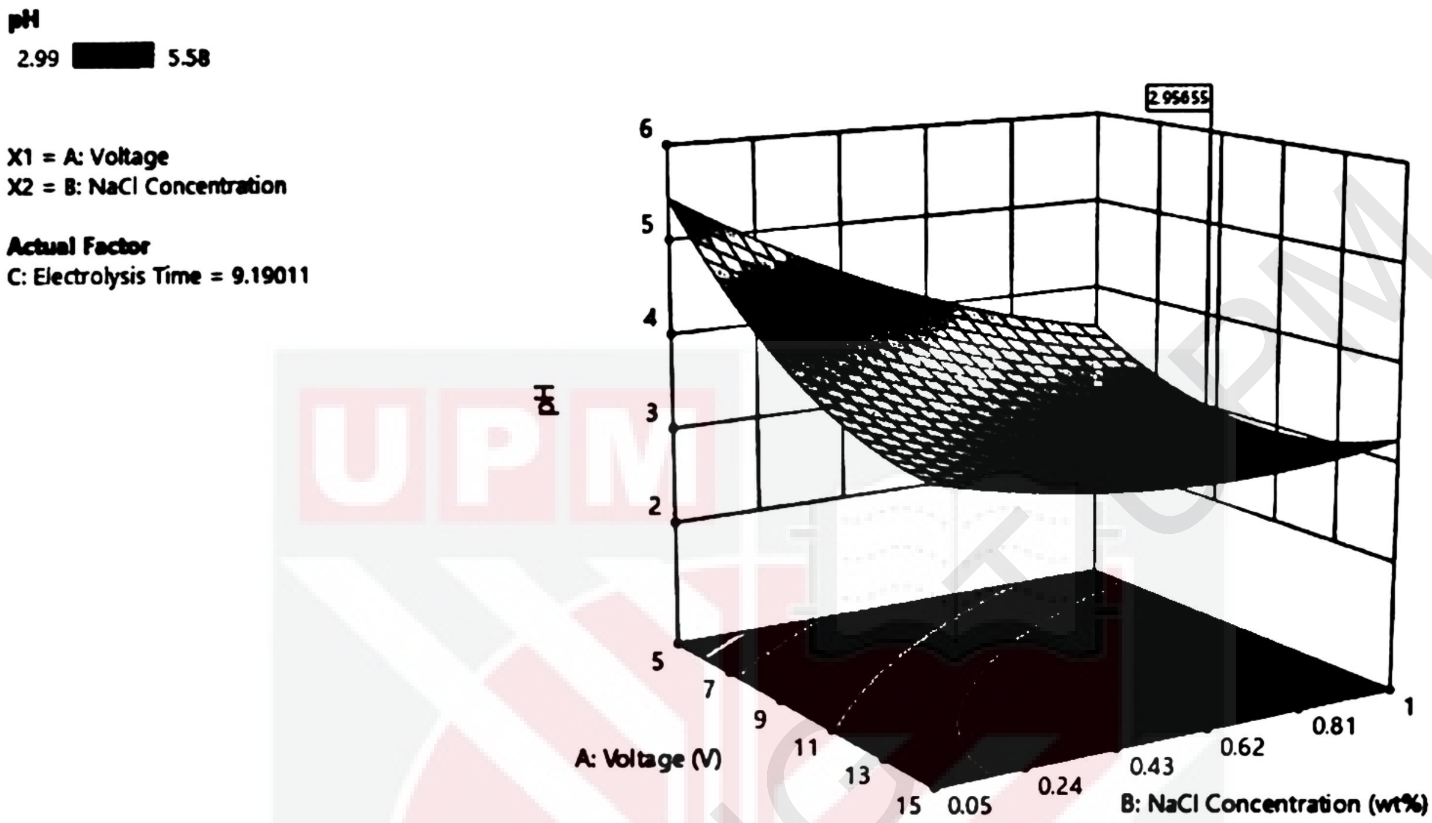
Based on the numerical optimization, for Titanium-SS316 AcEW the desirability function generated the predicted optimum condition at maximum desirability index 0.208 (0.21%) and for Titanium-SS316 AlEW the maximum desirability index 0.255 (0.26%) was obtained.

Table 4.12 : The optimized condition for AcEW

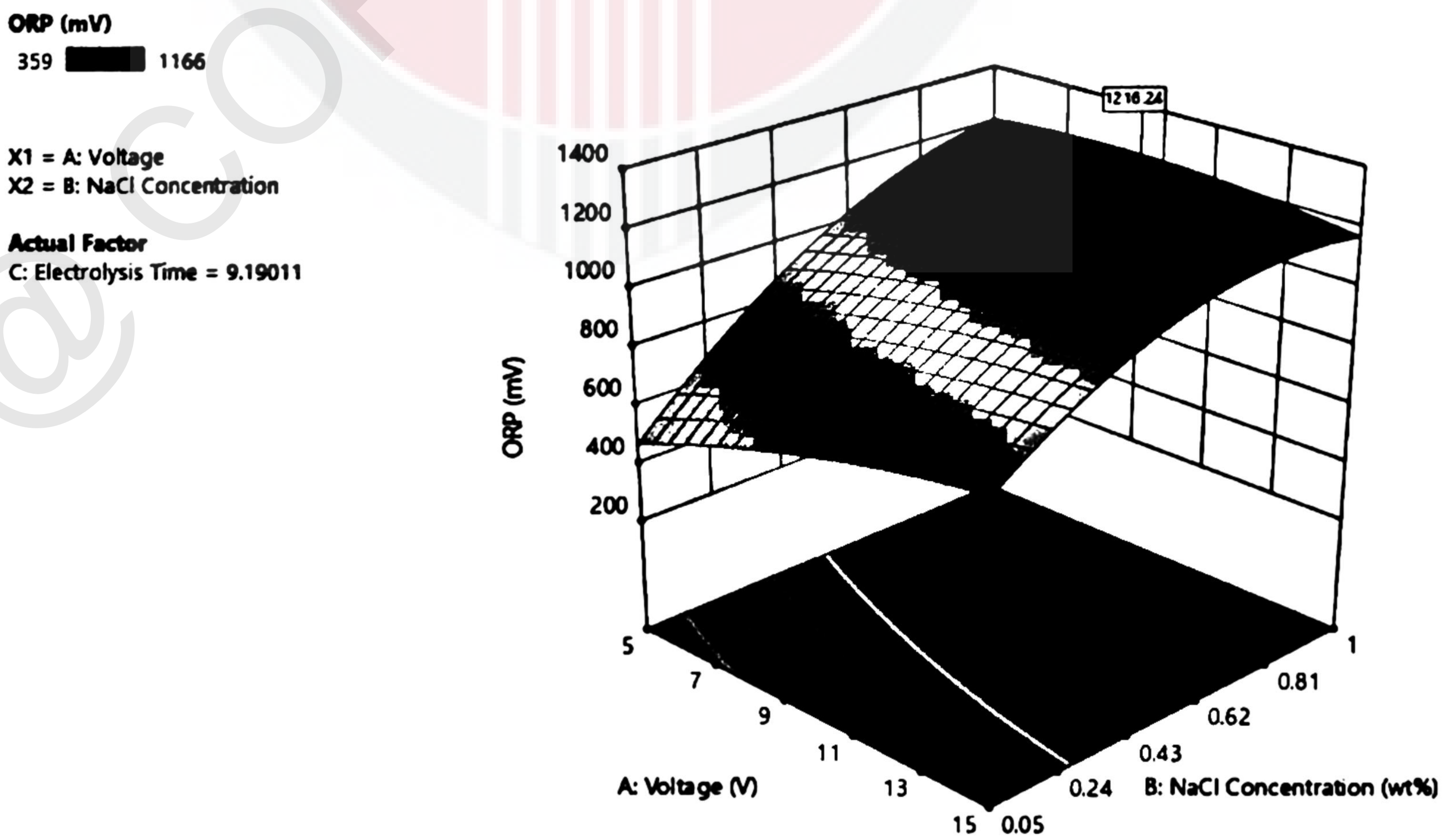
Variable			Response				
Voltage (V)	**NaCl Concentration (wt%)**	**Electrolysis Time (mins)**	**pH**	**ORP (mV)**	**Free Chlorine Content (mg/L)**	**Desira-bility**	
11.521	**0.824**	**9.19**	**2.957**	**1216.237**	**16.267**	**0.208**	**Selected**

From the desirability approach that obtained for Titanium-SS316 AcEW, the predicted optimum condition for factors variable is at 0.8 wt% NaCl concentration, 11.52 V and 9.19mins electrolysis time process in order to gain the optimum values of responses with 2.96 pH, 1216.237mV ORP and 16.27 mg/L free chlorine. There are some compromises are necessary to satisfy criteria if the desirability is approaching zero.

a)


pH
2.99 5.58
X1 = A: Voltage
X2 = B: NaCl Concentration
Actual Factor
C: Electrolysis Time = 9.19011
2.95655
6
5
4
3
2
pH
5
7
9
11
13
15
A: Voltage (V)
0.05
0.24
0.43
0.62
0.81
1
B: NaCl Concentration (wt%)

b)


ORP (mV)
359 1166
X1 = A: Voltage
X2 = B: NaCl Concentration
Actual Factor
C: Electrolysis Time = 9.19011
1216.24
1400
1200
1000
800
600
400
200
ORP (mV)
5
7
9
11
13
15
A: Voltage (V)
0.05
0.24
0.43
0.62
0.81
1
B: NaCl Concentration (wt%)

c)

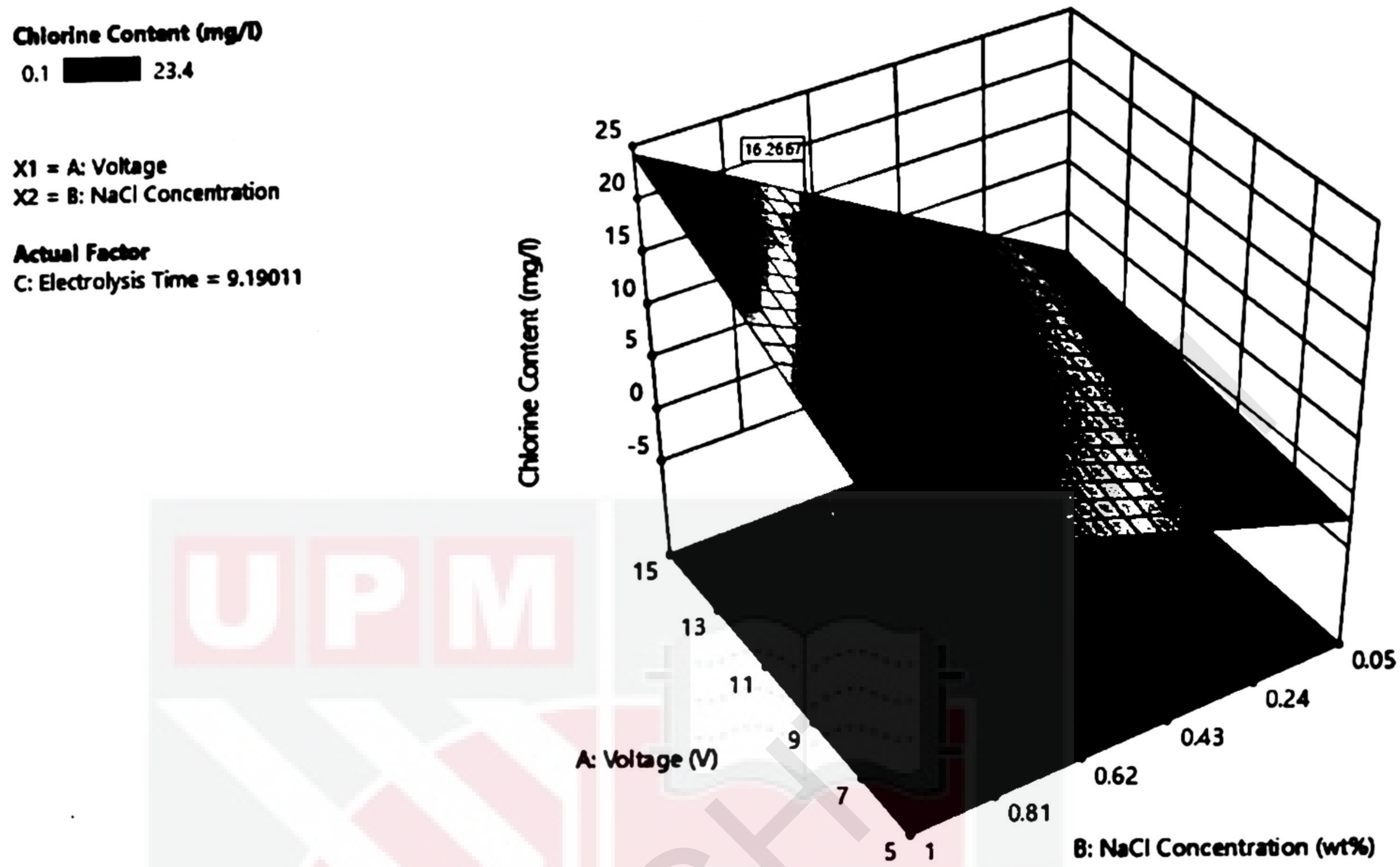


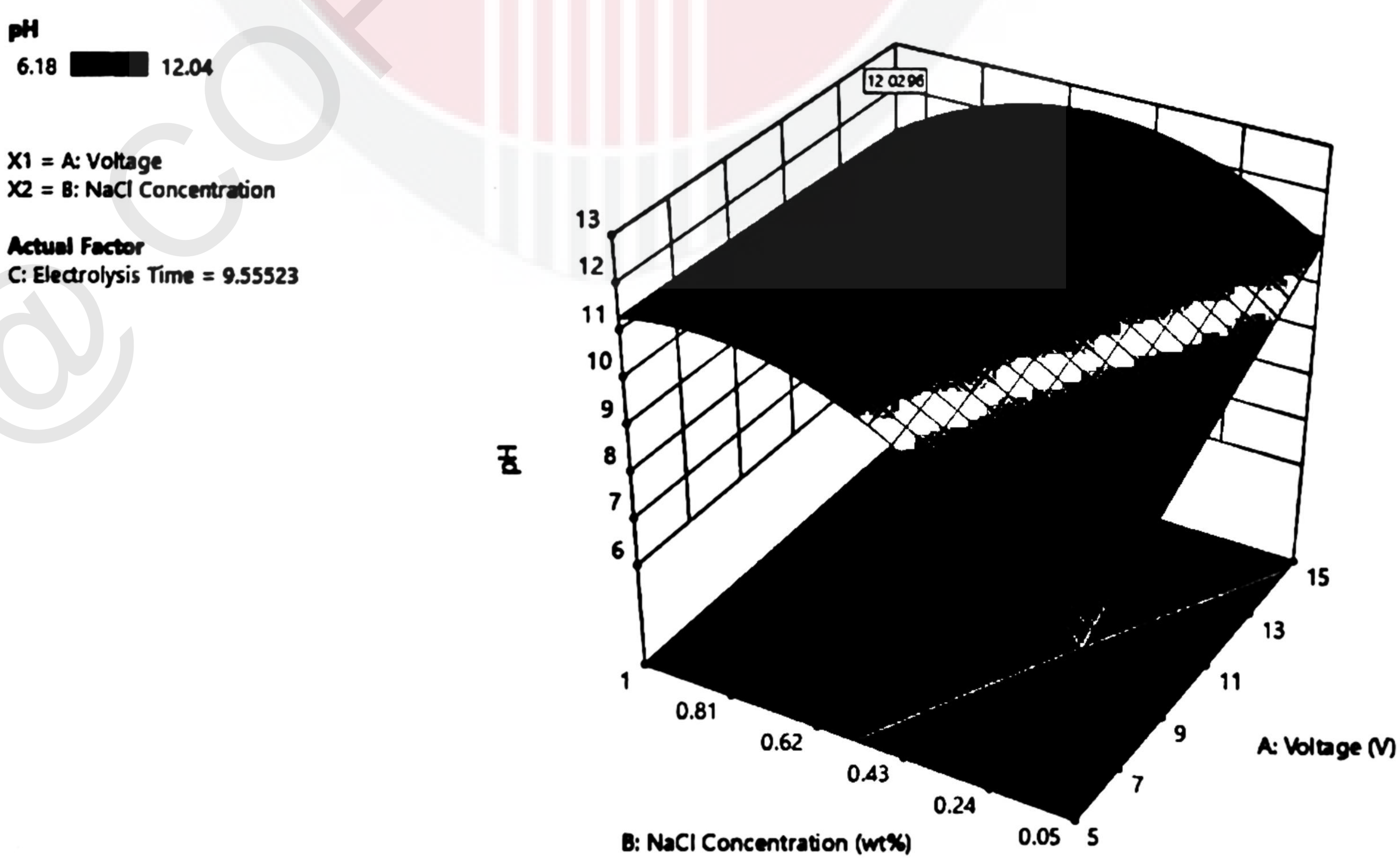
Figure 4.1 : Analysis graph profile for Titanium-SS316 of factors A: NaCl concentration and B : Elctrolysis Time vs. (a) pH, (b) Oxidation-Reduction Potential, (c) free chlorine

From the desirability approach that obtained for Titanium-SS316 AlEW, the predicted optimum condition for factors variable is at 0.75 wt% NaCl concentration, 11.80 V and 9.56mins electrolysis time in order to gain the optimum values of responses with 12.03 pH and -728.454mV ORP.

Table 4.13 : The optimized condition for AlEW

Variable			**Response**			
Voltage (V)	**NaCl Concentration (wt%)**	**Electrolysis Time (mins)**	**pH**	**ORP (mV)**	**Desira-bility**	
11.804	**0.747**	**9.555**	**12.03**	**-728.454**	**0.255**	**Selected**

a)



b)

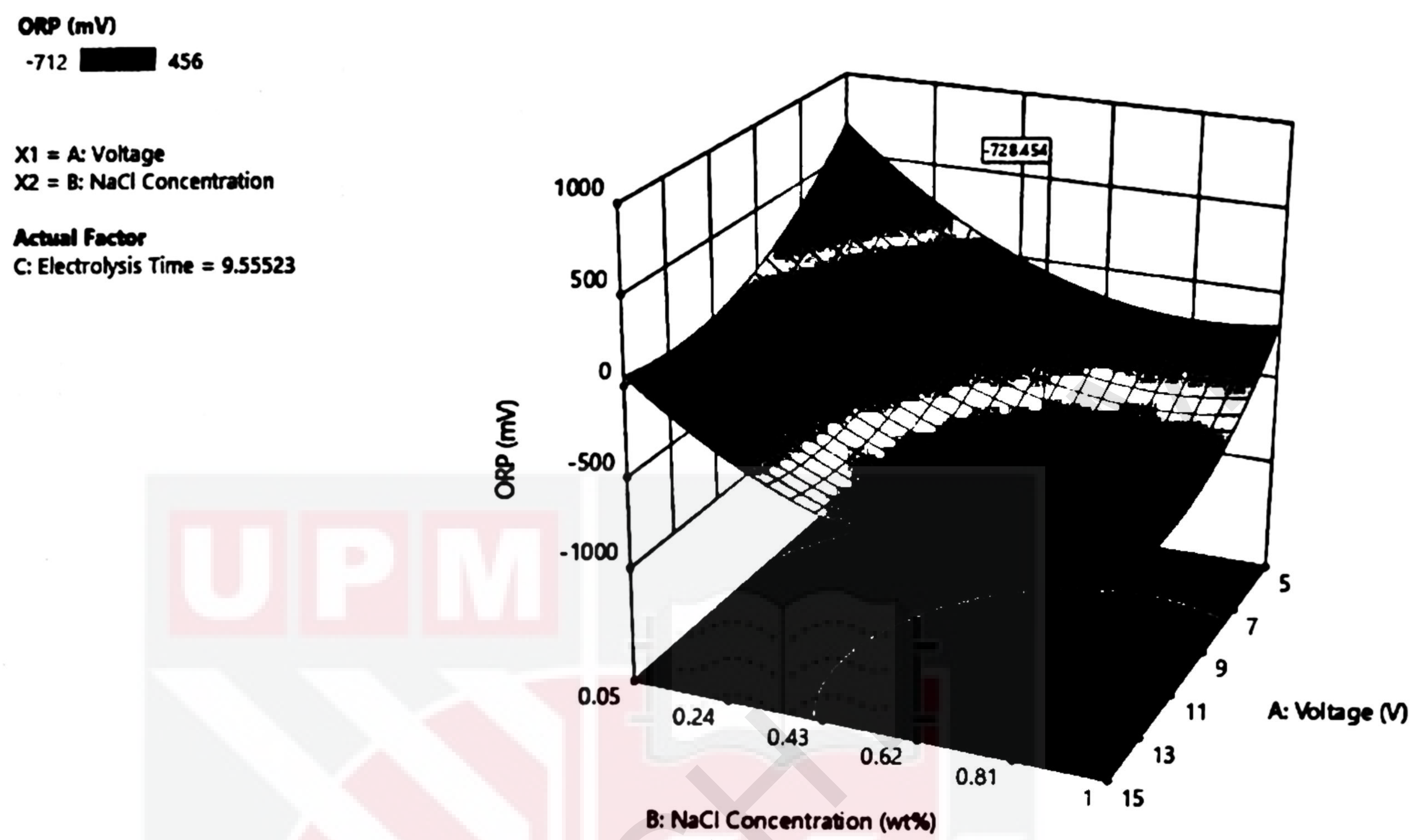


Figure 4.2 :Analysis graph profile for Titanium-SS316 of factors A: NaCl concentration and B : Elctrolysis Time vs. (a) pH, (b) Oxidation-Reduction Potential

4.6 Experimental Validation for Optimization of Electrolyzed Water

Data measured and experimental data was compared to confirm the data precision by conducting validation experiment and validation analyses. Hence, at oprtimized conditions the validation experiment was performed. The results from numerical optimization are validate by using lab scale elctrolyzing unit. Three factors (NaCl concentration, Voltage and Electrolysis time) need to be consider in order to achieve the optimal condition for the responses (pH, ORP, Free chlorine content).

Based on the numerical optimization by using pairing Titanium-SS316, the optimal condition would be 11.52V, 0.82 wt%, NaCl concentration and 9.19 mins for AcEW was producing a pH of 2.96, 1234.2mV, and 16.27mg/L free chlorine. Meanwhile, for AlEW, the optimal condition are 11.55V, 0.76 wt% NaCl and 9.43 mins where producing pH of 12.08 and -742.31mV. To validate the data, an experiment was carried out twice under optimized condition.

Table 4.14 : Predicted, experimental and error responses for optimization of Titanium-SS316 AcEW

Responses	Values		
	Predicted	**Experimental**	**Error (%)**
pH	2.957	2.91 ± 0.05	2
ORP	1234.2	1194 ± 0.05	3
Free Chlorine Content	16.269	13.8 ± 0.05	15

Table 4.15 : Predicted, experimental and error responses for optimization of Titanium-SS316 AlEW

Responses	Values		
	Predicted	Experimental	Error (%)
pH	12.087	11.785 ± 0.05	3
ORP	-742.313	-792 ± 0.05	7

Table 4.14 & 4.15 shows the predicted, experimental and error responses for optimization of Titanium-SS316 for AcEW and AlEW. The percentage error for pH, ORP and chlorine content was calculated. The value of error are slightly small where for AcEW is only 2%, 3% and 15% while for AlEW the error percentage is only 3% and 7%. Khalid et al. (2020) stated that the error is due to the dirty membrane, there is brown precipitate deposited on the ion-exchange membrane surface and insufficient of ion exchange.

4.7 Life cycle of electrode

4.7.1 Effect of electrolysis on the weight of electrode and chlorine content

According to (Natarajan, 2018) & (Jeong et al., 2009) platinum electrode is the best option in producing high efficiency electrolyzed water due to the platinum has the higher current density that will generate more chlorine content in EW. However, the cost of platinum electrode is too expensive and not applicable on this study. Titanium and also stainless steel electrode relatively have cheaper cost and can produce electrolyzed water with high efficiency. The electrolysis process is carried out using optimimum condition of AcEW consisted of 0.82 wt% Nacl concentration at 9.19 mins and 11.52V. The experiment was carried out for 7 days and placed inside the dessicator for 24 hours storage after electrolysis. At anode the stainless steel 316 material electrodes and at cathode titanium material electrode were used. During day 7 no electrolysis process are run hence there is no results for day 7.

Table 4.16 : Weight of electrode and chlorine content generated

Day	Weight (g)		Chlorine content
	Anode	Cathode	(mg/L)
1	153.85	87.52	14.64
2	153.57	87.48	14.03
3	153.34	87.48	13.27
4	153.18	87.46	12.65
5	152.89	87.42	11.87
6	152.67	87.38	11.05
7	152.31	87.37	-

The weight of electrode decreases from day 1 to day 7. The chlorine content also decreases as the weight of the electrode decreased. From Table 4.16, shows the weight of electrode and the chlorine content after electrolysis process for 7 days. Khalid et al. (2020) stated that corrosion causes the membrane used is accumulated with the fouling deposit from electrode and inhibit the ion exchange between the electrodes. Hence, it causes the production of chlorine is lowered. Therefore, the precipitate formed are from electrodes resulting the weight of the electrode is reduced and restrain the chlorine production.

4.7.2 Corrosion rates of electrodes

Table 4.17 : Rate of corrosion at anode and cathode electrode

Day	R_c ($gcm^{-2}h^{-1}$)	
	Anode	Cathode
1	0.019	0.003
2	0.015	0.00
3	0.012	0.001
4	0.019	0.003
5	0.015	0.003
6	0.024	0.001
7	-	-

Rate of corrosion is rate or speed of the metal to deteriorate in particular condition. It is depending on the type of metal and environmental condition. Corrosion rate was calculated using the weight difference per surface area and immersed time.

Palit (2018) explained more active metal is placed at anode since it corrode faster while noble metal is placed at cathode as it corrode slower. In this case, titanium is noble metal and stainless steel is active thus this electrodes are placed at cathode and anode respectively. Therefore, table 4.17 shows that rate of corrosion of stainless steel electrode is higher than titanium electrode where the range value is between (0.012 to 0.024 $gcm^{-2}h^{-1}$) for stainless steel electrode and for titanium electrode the ranges is between (0.00-0.003 $gcm^{-2}h^{-1}$). Although corrosion still occurs, the rate of corrosion of both electrodes are still considerable and acceptable.

4.8 Summary

Study of the effect of electrolyzing parameters NaCl concentration (0.05, 0.53, 1.0wt%), Voltage (9, 16, 24 V), electrolysis time (5, 7.5, 10.minutes) is performed to observe the performance of pH, ORP, free chlorine, total chlorine and temperature for production of electrolyzed water. The results of physical and chemical properties (pH, ORP, free chlorine and total chlorine) from the lab work by using lab scale electrolyzing unit is analysed and optimized using Response Surface Methodology (RSM). From the result, Titanium-Stainless steel 316 is selected as the best materials of electrodes pairing because has highest chlorine production compared to another pairing. The optimized condition for AcEW is obtained when 0.82 wt% NaCl concentration, 9.19 mins electrolysis time and 11.52 V to produce pH of 2.96, 1234.2 mV and 16.27 mg/L of chlorine content. Meanwhile, the optimal condition of AlEW consisted of 0.76 wt% NaCl concentration, 9.43 mins electrolysis time and 11.55 V to produce pH of 12.09 and -742.31 mV.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

A conclusion on field study and some recommendation for future studies in optimization of electrolyzed water with high efficiency in cleaning and sanitation process has been proposed in this chapter. This study was carried out to generate optimal condition of AcEW and AlEW. A laboratory scale electrolyzing unit is used in this study, in order to investigate the effect electrolyzing parameters (NaCl concentration, electrode materials, electrolysis time and voltage) on physical and chemical properties properties of electrolyzed water.

5.1 Conclusion on design of experiment

Nowadays, food manufacturer are concerning the negative impacts of using industrial chemical during cleaning and sanitizing that might contaminate the food product and resulting in some dentrimental effect to the food manufactures. Hence, an effective cleaning and sanitizing medium are well required. Over past years, electrolyzed water has been considered as a new green sanitizer and cleaner in replacing the existed chemical cleaner due to the beneficial effect (cheaper, save storage, safe on food product and environmental friendly) of usage electrolyzed water. EW has the ability to be more efficient and cost effective than the traditional and cleaning agents. Moreover, EW is less harmful to environment and safe to use in application of food industry at the same time as an alternative green cleaning and sanitizing medium available today.

Laboratory scale electrolyzing unit used in this study in determining the relationship between electrolyzing parameter and physical-chemical properties. From this study, Titanium-SS316 (cathode-anode) is choosen due to the fact that it has high current efficiency that will generate more chlorine content therefore it will improve the effectiveness of the electrolyzed water. RSM analysis indicated good agreement between the predicted and experimental.

From RSM, the optimized condition for AcEW is obtained when 0.82 wt% NaCl concentration, 9.19 mins electrolysis time and 11.52 V to produce pH of 2.96, 1234.2 mV and 16.27 mg/L of chlorine content. Meanwhile, the optimal condition of AlEW consisted of 0.76 wt% NaCl concentration, 9.43 mins electrolysis time and 11.55 V to produce pH of 12.09 and -742.31 mV.

The rates of corrosion of Titanium-SS316 pairing is very low where rates of corrosion occurs for titanium at cathode side only between (0.00-0.003 $gcm^{-2}h^{-1}$) meanwhile for stainless steel at anode the corrosion rates is (0.012 to 0.024 $gcm^{-2}h^{-1}$). Hence, by using Titanium-SS316 pairing during electrolysis, the effect corrosion on the physical and chemical properties of electrolyzed can be minimized.

The electrolyzed water produced using the optimum condition of electrolyzing parameter has high efficiency to kill foodborne pathogens. Moreover, the low rates of corrosion occurs during the electrolysis enhance the ability of the electrolyzed water as a green cleaner and sanitizer. Thus, application of electrolyzed water in food industry especially for Small to Medium Enterprise (SME) brings many benefit in reducing the cleaning and sanitation cost, safe for food product at the same it is environmental friendly.

5.1.1 Recommendation of future works

The trends of data observed might not increase and decrease smoothly due to the low current efficiency of the electrode pairing materials. This is the reason why the electrolyzed water produced generate the low amount of chlorine content. The electrodes pairing materials used should have low cost and follow the galvanic series in avoiding the corrosion occurs during electrolysis process. For the future study, can use another type of electrodes such as stainless steel titanium or different grades of stainless steel that have different percentage of molydenum content. Also, the consideration on the pulsing mode of electrolysis should be apply for future work. Validation using the AcEW and AlEW to clean and sanitize food contact surfaces (plastic, stainless steel, cutting board (bamboo, plastic)) which inoculated with foodborne pathogens such as Escherichia coli, Listeria monocytogenes & Salmonella typhimurium can be done for future study. In addition, cleaning and sanitation of food contact surfaces that accumulated with different type of deposit, for instance carbohydrates-based (juices and puree), protein (dairy), mineral (milk), fat (oil grease) are also proposed for future study

Continuous or circulation lab based electrolysis unit should be designed and fabricated for future study. Further modification and recommendation of this electrolyzed water system can be performed to achieve optimal condition.

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APPENDICES

TABLE OF RESULTS

Repetition 1

Table 1 : Acidic Electrolyzed Water (Titanium)

NaCl Concent. (wt.%)	Volt. (V)	Amp. (A)	pH			[redacted]												
			Bef.	Aft.	Diff.	Bef.	Aft.	Diff.	Aft.	Aft.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.
5 Minutes																			
0.53	5	0.42	6.94	5.67	1.27	229	336	(107)	0.32	0.30	6.3	5.2	1.1	8.49	8.58	(0.09)	27.3	26.7	0.6
0.05	10	0.19	6.00	5.30	0.70	381	380	1	0.09	0.19	6.2	5.0	1.2	1.19	0.96	0.23	27.7	27.3	0.4
1.00	10	2.13	5.83	3.95	1.88	422	973	(551)	4.56	4.33	6.4	5.2	1.2	14.68	16.74	(2.06)	28.0	26.7	1.3
0.53	15	2.38	8.19	4.53	3.66	482	886	(404)	0.79	0.82	6.0	5.0	1.0	8.95	8.85	0.10	27.0	26.5	0.5
7.5 Minutes																			
0.05	5	0.07	6.77	5.04	1.73	537	470	67	0.05	0.14	6.3	5.2	1.1	1.29	1.03	0.26	27.5	27.3	0.2
1.00	5	0.75	5.76	3.86	1.90	398	1089	(691)	6.10	10.40	6.3	5.1	1.2	15.42	16.48	(1.06)	27.4	26.7	0.7
0.53	10	1.26	6.84	3.75	3.09	650	1067	(417)	4.92	5.11	6.0	5.0	1.0	9.11	9.16	(0.05)	27.7	27.4	0.3
0.53	10	1.30	6.91	3.69	3.22	613	1002	(389)	9.00	10.40	6.2	5.1	1.1	8.86	9.34	(0.48)	28.4	27.3	1.1
0.53	10	1.26	6.92	3.61	3.31	549	1042	(493)	7.90	8.50	6.1	5.0	1.1	8.86	9.14	(0.28)	28.4	27.7	0.7
0.53	10	1.31	8.33	3.44	4.89	417	1098	(681)	9.30	9.00	6.0	5.0	1.0	8.65	9.06	(0.41)	27.5	27.3	0.2
0.53	10	1.34	7.90	3.26	4.64	473	1122	(649)	10.70	12.70	6.1	5.0	1.1	8.94	8.77	0.17	27.9	27.1	0.8
0.05	15	0.28	6.40	3.23	3.17	501	896	(395)	1.33	1.34	6.3	5.1	1.2	1.24	1.10	0.14	26.7	25.7	1.0
1.00	15	3.85	6.29	3.66	2.63	555	1122	(567)	12.70	16.00	6.4	5.3	1.1	15.83	16.40	(0.57)	26.5	26.0	0.5
10 Minutes																			
0.53	5	0.43	6.75	4.44	2.31	462	1011	(549)	2.14	4.32	6.3	5.1	1.2	9.12	8.95	0.17	28.3	27.1	1.2
0.05	10	0.18	6.60	4.13	2.47	606	538	68	0.15	0.17	6.0	5.0	1.0	1.18	1.05	0.13	26.3	25.9	0.4
1.00	10	2.24	5.87	3.11	2.76	433	1163	(730)	24.90	25.30	6.1	5.1	1.0	15.40	17.00	(1.60)	27.7	26.6	1.1
0.53	15	2.37	7.55	3.03	4.52	606	1156	(550)	11.70	11.90	6.0	5.0	1.0	9.20	9.46	(0.26)	27.9	26.9	1.0

Table 2 : Alkaline Electrolyzed Water (Titanium)

NaCl Concent. (wt.%)	Volt. (V)	Amp. (A)	pH			ORP (mV)			Free Chlorine (mg/l)	Total Chlorine (mg/l)	DO			[redacted] (Sm)			[redacted]		
			Bef.	Aft.	Diff.	Bef.	Aft.	Diff.	Aft.	Aft.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.
5 Minutes																			
0.53	5	0.42	6.94	10.37	(3.43)	229	120	109			6.3	5.1	1.2	8.49	8.01	0.48	27.3	26.8	0.5
0.05	10	0.19	6.00	6.16	(0.16)	381	314	67			6.2	5.0	1.2	1.19	0.93	0.26	27.7	27.4	0.3
1.00	10	2.13	5.83	11.31	(5.48)	422	-144	566			6.4	5.3	1.1	14.68	16.59	(1.91)	28.0	27.6	0.4
0.53	15	2.38	8.19	11.21	(3.02)	482	-72	554			6.0	5.0	1.0	8.95	9.04	(0.09)	27.0	27.2	(0.2)
7.5 Minutes																			
0.05	5	0.07	6.77	6.47	0.30	537	441	155			6.3	5.2	1.1	1.29	0.97	0.32	27.5	27.5	0.0
1.00	5	0.75	5.76	11.19	(5.43)	398	-96	494			6.3	5.1	1.2	15.42	16.66	(1.24)	27.4	27.2	0.2
0.53	10	1.26	6.84	11.35	(4.51)	650	-507	1157			6.0	5.0	1.0	9.11	9.35	(0.24)	27.7	28.0	(0.3)
0.53	10	1.3	6.91	11.44	(4.53)	613	-164	777			6.2	5.1	1.1	8.86	9.31	(0.45)	28.4	28.3	0.1
0.53	10	1.26	6.92	12.45	(5.53)	549	-655	1204			6.1	5.1	1.0	8.86	9.30	(0.44)	28.4	28.2	0.2
0.53	10	1.31	8.33	11.65	(3.32)	417	-321	738			6.0	5.0	1.0	8.65	8.65	0.00	27.5	27.7	(0.2)
0.53	10	1.34	7.90	11.06	(3.16)	473	-160	633			6.1	5.1	1.0	8.94	9.28	(0.34)	27.9	28.1	(0.2)
0.05	15	0.28	6.40	11.04	(4.64)	501	218	283			6.3	5.2	1.1	1.24	9.40	(8.16)	26.7	28.2	(1.5)
1.00	15	3.85	6.29	11.55	(5.26)	555	-124	679			6.4	5.2	1.2	15.83	16.38	(0.55)	26.5	26.6	(0.1)
10 Minutes																			
0.53	5	0.43	6.75	11.05	(4.30)	462	19	443			6.3	5.1	1.2	9.12	9.01	0.11	28.3	27.3	1.0
0.05	10	0.18	6.60	9.51	(2.91)	606	221	385			6.0	5.0	1.0	1.18	0.91	0.27	26.3	26.0	0.3
1.00	10	2.24	5.87	11.58	(5.71)	433	-754	1187			6.1	5.0	1.1	15.40	16.38	(0.98)	27.7	27.0	0.7
0.53	15	2.37	7.55	11.93	(4.38)	606	-611	1217			6.0	5.0	1.0	9.20	9.50	(0.30)	27.9	27.6	0.3

Repetition 2

Table 3 : Acidic Electrolyzed Water (Titanium)

NaCl Concent. (wt.%)	Volt. (V)	Amp. (A)	pH			ORP (mV)			Free Chlorine (mg/l)	Total [redacted] (mg/l)	DO			[redacted]			[redacted] (°C)		
			Bef.	Aft.	Diff.	Bef.	Aft.	Diff.	Aft.	Aft.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.
5 Minutes																			
0.53	5	0.44	6.17	5.47	0.70	332	382	(50)	0.19	0.45	6.4	5.3	1.1	8.61	8.57	0.04	28.1	27.8	0.3
0.05	10	0.18	5.88	4.94	0.94	373	397	(24)	0.12	0.17	6.2	5.0	1.2	0.96	0.85	0.11	29.8	28.7	1.1
1.00	10	2.1	7.08	4.1	2.98	601	957	(356)	3.1	3.63	6.0	5.0	1.0	16.16	16.70	(0.54)	27.1	26.4	0.7
0.53	15	2.32	6.97	4.11	2.86	339	968	(629)	1.48	1.53	6.2	5.1	1.1	8.88	8.70	0.18	27.6	26.3	1.3
7.5 Minutes																			
0.05	5	0.07	6.22	6.11	0.11	431	426	5	0.11	0.16	6.3	5.3	1.0	0.95	0.92	0.03	27.2	26.8	0.4
1.00	5	0.85	7.18	3.8	3.38	519	1105	(586)	6.31	9.8	6.1	5.0	1.1	16.33	16.42	(0.09)	27.3	26.9	0.4
0.53	10	1.28	6.18	3.3	2.88	388	1082	(694)	6.2	7.1	6.0	5.0	1.0	8.81	9.36	(0.55)	30.3	28.0	2.3
0.53	10	1.24	7.07	3.57	3.50	470	1008	(538)	5.9	11.6	6.2	5.1	1.1	8.79	8.75	0.04	27.2	26.8	0.4
0.53	10	1.21	5.74	3.57	2.17	505	1022	(517)	4.3	5.7	6.0	5.0	1.0	9.07	8.84	0.23	26.9	26.2	0.7
0.53	10	1.27	6.28	3.41	2.87	529	1080	(551)	8.3	10.2	6.0	5.0	1.0	8.94	9.23	(0.29)	28.2	27.0	1.2
0.53	10	1.25	6.64	3.16	3.48	652	1168	(516)	10	11.5	6.1	5.0	1.1	8.74	9.10	(0.36)	28.4	27.0	1.4
0.05	15	0.25	5.95	4.18	1.77	709	830	(121)	0.56	0.64	6.3	5.2	1.1	0.99	0.97	0.02	26.3	25.3	1.0
1.00	15	4.24	8.73	3.48	5.25	617	1146	(529)	18.4	22.5	6.4	5.2	1.2	16.24	16.99	(0.75)	26.0	25.5	0.5
10 Minutes																			
0.53	5	0.43	6.55	3.97	2.58	297	1025	(728)	2.28	4.5	6.3	5.1	1.2	8.80	8.95	(0.15)	27.2	26.3	0.9
0.05	10	0.18	5.91	4.23	1.68	466	521	(55)	0.13	0.19	6.1	5.1	1.0	0.92	0.94	(0.02)	26.9	26.1	0.8
1.00	10	2.4	8.50	2.91	5.59	573	1168	(595)	21.9	22.4	6.0	5.0	1.0	16.21	17.49	(1.28)	27.8	28.1	(0.3)
0.53	15	2.41	8.44	2.94	5.50	560	1159	(599)	11.4	11.88	6.2	5.1	1.1	8.97	9.34	(0.37)	28.3	28.0	0.3

Table 4 : Alkaline Electrolyzed Water (Titanium)

NaCl Concent. (wt.%)	Volt. (V)	Amp. (A)	pH			ORP (mV)			Free Chlorine (mg/l)	Total Chlorine (mg/l)	DO			[redacted]					
			Bef.	Aft.	Diff.	Bef.	Aft.	Diff.	Aft.	Aft.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.
5 Minutes																			
0.53	5	0.44	6.17	9.95	(3.78)	332	135	197			6.4	5.2	1.2	8.61	8.61	0.00	28.1	27.9	0.2
0.05	10	0.18	5.88	6.2	(0.32)	373	346	27			6.2	5.1	1.1	0.96	0.88	0.08	29.8	29.6	0.2
1.00	10	2.1	7.08	11.29	(4.21)	601	-174	775			6.0	5.0	1.0	16.16	16.63	(0.47)	27.1	27.2	(0.1)
0.53	15	2.32	6.97	11.16	(4.19)	339	-53	392			6.2	5.0	1.2	8.88	9.24	(0.36)	27.6	27.8	(0.2)
7.5 Minutes																			
0.05	5	0.07	6.22	6.49	(0.27)	431	471	(40)			6.3	5.2	1.1	0.95	0.92	0.03	27.2	27.0	0.2
1.00	5	0.85	7.18	11.19	(4.01)	519	-94	613			6.1	5.1	1.0	16.33	16.60	(0.27)	27.3	27.6	(0.3)
0.53	10	1.28	6.18	11.35	(5.17)	388	-749	1137			6.0	5.0	1.0	8.81	9.39	(0.58)	30.3	29.3	1.0
0.53	10	1.24	7.07	11.5	(4.43)	470	-208	678			6.2	5.0	1.2	8.79	9.22	(0.43)	27.2	27.4	(0.2)
0.53	10	1.21	5.74	11.62	(5.88)	505	-508	1013			6.0	5.0	1.0	9.07	9.72	(0.65)	26.9	26.2	0.7
0.53	10	1.27	6.28	11.71	(5.43)	529	-733	1262			6.0	5.0	1.0	8.94	9.38	(0.44)	28.2	27.4	0.8
0.53	10	1.25	6.64	11.20	(4.56)	652	-756	1408			6.1	5.1	1.0	8.74	9.17	(0.43)	28.4	27.7	0.7
0.05	15	0.25	5.95	10.75	(4.80)	709	180	529			6.3	5.1	1.2	0.99	0.96	0.03	26.3	26.0	0.3
1.00	15	4.24	8.73	11.69	(2.96)	617	-135	752			6.4	5.2	1.2	16.24	16.87	(0.63)	26.0	26.4	(0.4)
10 Minutes																			
0.53	5	0.43	6.55	10.93	(4.38)	297	13	284			6.3	5.2	1.1	8.80	8.80	0.00	27.2	26.7	0.5
0.05	10	0.18	5.91	9.03	(3.12)	466	234	232			6.1	5.0	1.1	0.92	0.87	0.05	26.9	26.3	0.6
1.00	10	2.4	8.50	11.69	(3.19)	573	-670	1243			6.0	5.0	1.0	16.21	17.28	(1.07)	27.8	28.4	(0.6)
0.53	15	2.41	8.44	11.79	(3.35)	560	-768	1328			6.2	5.1	1.1	8.97	9.47	(0.50)	28.3	28.6	(0.3)

Repetition 1

Table 5 : Acidic Electrolyzed Water (Nickel)

NaCl Concent. (wt.%)	Volt. (V)	Amp. (A)	pH			[redacted] (mV)			[redacted] (mg/l)	Total Chlorine (mg/l)	DO			[redacted]					
			Bef.	Aft.	Diff.	Bef.	Aft.	Diff.	Aft.	Aft.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.
5 Minutes																			
0.53	5	0.50	5.56	5.74	(0.18)	275	281	(6)	0.13	0.20	6.0	5.0	1.0	8.10	8.30	(0.20)	27.0	26.7	0.3
0.05	10	0.18	6.08	5.66	0.42	231	247	(16)	0.08	0.10	6.3	5.2	1.1	1.23	0.98	0.25	27.6	26.8	0.8
1.00	10	2.48	5.60	4.40	1.20	329	382	(53)	0.13	0.60	6.1	5.1	1.0	14.43	16.19	(1.76)	27.0	26.2	0.8
0.53	15	2.40	6.30	5.48	0.82	236	260	(24)	0.14	0.42	6.4	5.3	1.1	8.77	8.76	0.01	26.6	25.8	0.8
7.5 Minutes																			
0.05	5	0.08	6.67	5.71	0.96	223	286	(63)	0.07	0.52	6.2	5.1	1.1	1.19	0.92	0.27	29.1	28.0	1.1
1.00	5	1.08	6.74	6.26	0.48	284	209	75	0.27	0.23	6.0	5.0	1.0	13.42	15.47	(2.05)	25.9	25.3	0.6
0.53	10	1.36	6.78	6.20	0.58	198	192	6	0.23	0.35	6.1	5.0	1.1	8.74	8.88	(0.14)	25.4	24.7	0.7
0.53	10	1.36	6.52	6.05	0.47	209	190	19	0.36	0.35	6.3	5.2	1.1	8.58	8.81	(0.23)	26.5	25.6	0.9
0.53	10	1.30	5.98	5.67	0.31	205	246	(41)	0.35	0.66	6.2	5.1	1.1	8.66	8.73	(0.07)	26.7	26.4	0.3
0.53	10	1.31	6.62	5.90	0.72	249	218	31	0.18	0.40	6.4	5.2	1.2	8.54	8.61	(0.07)	25.9	26.4	(0.5)
0.53	10	1.30	6.58	5.56	1.02	245	262	(17)	0.33	0.38	6.3	5.1	1.2	8.77	8.80	(0.03)	29.4	27.8	1.6
0.05	15	0.28	6.54	6.25	0.29	232	277	(45)	0.32	0.36	6.0	5.0	1.0	1.22	0.97	0.25	27.5	26.3	1.2
1.00	15	3.18	6.23	4.16	2.07	276	348	(72)	0.14	0.43	6.1	5.0	1.1	15.14	16.49	(1.35)	26.3	25.9	0.4
10 Minutes																			
0.53	5	0.58	7.36	6.51	0.85	259	254	5	0.29	0.30	6.2	5.1	1.1	8.75	8.67	0.08	23.1	27.4	(4.3)
0.05	10	0.23	6.12	6.33	(0.21)	227	245	(18)	0.13	0.26	6.1	5.0	1.1	1.40	1.07	0.33	28.1	27.0	1.1
1.00	10	1.80	6.44	4.73	1.71	264	306	(42)	0.20	0.34	6.0	5.0	1.0	15.51	16.86	(1.35)	26.6	25.9	0.7
0.53	15	1.80	6.64	4.91	1.73	293	275	18	0.31	0.70	6.1	5.1	1.0	8.99	9.12	(0.13)	28.9	27.7	1.2

Table 6 : Alkaline Electrolyzed Water (Nickel)

NaCl Concent. (wt.%)	Volt. (V)	Amp. (A)	pH			ORP (mV)			Free Chlorine (mg/l)	Total Chlorine (mg/l)	DO			[redacted]					
			Bef.	Aft.	Diff.	Bef.	Aft.	Diff.	Aft.	Aft.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.
5 Minutes																			
0.53	5	0.5	5.56	9.89	(4.33)	275	98	177			6.0	5.0	1.0	8.10	8.33	(0.23)	27.0	26.7	0.3
0.05	10	0.18	6.08	6.29	(0.21)	231	220	11			6.3	5.1	1.2	1.23	0.93	0.30	27.6	27.5	0.1
1.00	10	2.48	5.60	11.92	(6.32)	329	-564	893			6.1	5.0	1.1	14.43	16.82	(2.39)	27.0	26.7	0.3
0.53	15	2.4	6.30	11.92	(5.62)	236	172	64			6.4	5.2	1.2	8.77	9.00	(0.23)	26.6	26.4	0.2
7.5 Minutes																			
0.05	5	0.08	6.67	6.25	0.42	223	240	(17)			6.2	5.1	1.1	1.19	0.99	0.20	29.1	28.2	0.9
1.00	5	1.08	6.74	11.3	(4.56)	266	-542	808			6.0	5.0	1.0	13.42	16.55	(3.13)	25.9	25.6	0.3
0.53	10	1.36	6.78	11.28	(4.50)	198	-394	592			6.1	5.0	1.1	8.74	9.00	(0.26)	25.4	25.3	0.1
0.53	10	1.36	6.52	11.48	(4.96)	209	-660	869			6.3	5.2	1.1	8.58	9.16	(0.58)	26.5	26.3	0.2
0.53	10	1.3	5.98	11.32	(5.34)	205	-258	463			6.2	5.0	1.2	8.66	9.27	(0.61)	26.7	26.3	0.4
0.53	10	1.31	6.62	11.34	(4.72)	249	-507	756			6.4	5.2	1.2	8.54	9.13	(0.59)	25.9	27.3	(1.4)
0.53	10	1.3	6.58	11.33	(4.75)	245	-387	632			6.3	5.1	1.2	8.77	9.35	(0.58)	29.4	28.4	1.0
0.05	15	0.28	6.54	10.52	(3.98)	232	7	225			6.0	5.0	1.0	1.22	1.02	0.20	27.5	27.0	0.5
1.00	15	3.18	6.23	11.55	(5.32)	276	-402	678			6.1	5.0	1.1	15.14	16.44	(1.30)	26.3	26.3	0.0
10 Minutes																			
0.53	5	0.58	7.36	10.92	(3.56)	259	-64	323			6.2	5.1	1.1	8.75	8.89	(0.14)	23.1	28.5	(5.4)
0.05	10	0.23	6.12	10.38	(4.26)	227	108	119			6.1	5.0	1.1	1.40	1.02	0.38	28.1	27.8	0.3
1.00	10	1.8	6.44	11.57	(5.13)	264	-797	1061			6.0	5.0	1.0	15.51	16.51	(1.00)	26.6	26.4	0.2
0.53	15	1.8	6.64	11.61	(4.97)	293	-764	1057			6.1	5.1	1.0	8.99	9.68	(0.69)	28.9	28.6	0.3

Repetition 2

Table 7 : Acidic Electrolyzed Water (Nickel)

NaCl Concent. (wt.%)	Volt. (V)	Amp. (A)	pH			(mV)			[redacted]									
			Bef.	Aft.	Diff.	Bef.	Aft.	Diff.	Aft.	Aft.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.
5 Minutes																		
0.53	5	0.56	6.22	5.65	0.57	256	224	32	0.13	0.14	6.4	5.2	1.2	8.23	8.25	(0.02)	26.6	26.4	0.2
0.05	10	0.18	5.79	5.69	0.10	280	272	8	0.12	0.41	6.3	5.1	1.2	0.87	0.87	0.00	27.5	27.1	0.4
1.00	10	2.47	6.03	4.57	1.46	266	393	(127)	0.17	0.33	6.1	5.0	1.1	14.84	11.12	3.72	26.1	25.3	0.8
0.53	15	2.48	6.18	6.02	0.16	240	201	39	0.08	0.25	6.1	5.1	1.0	8.55	8.79	(0.24)	27.2	26.3	0.9
7.5 Minutes																		
0.05	5	0.08	5.56	5.91	(0.35)	290	238	52	0.07	0.59	6.3	5.2	1.1	0.91	0.86	0.05	26.6	26.4	0.2
1.00	5	1.05	6.40	6.3	0.10	228	182	46	0.22	0.3	6.0	5.0	1.0	15.75	15.92	(0.17)	25.8	25.0	0.8
0.53	10	1.36	6.59	5.96	0.63	197	177	20	0.18	0.32	6.1	5.0	1.1	8.62	8.75	(0.13)	25.8	25.3	0.5
0.53	10	1.33	6.55	5.83	0.72	198	220	(22)	0.21	0.48	6.0	5.0	1.0	8.72	8.89	(0.17)	26.2	25.8	0.4
0.53	10	1.31	6.45	5.55	0.90	246	249	(3)	0.21	0.45	6.3	5.2	1.1	8.49	8.74	(0.25)	26.4	25.9	0.5
0.53	10	1.3	6.37	5.43	0.94	239	260	(21)	0.35	0.43	6.2	5.1	1.1	8.67	8.18	0.49	29.1	27.3	1.8
0.53	10	1.24	6.13	5.2	0.93	273	277	(4)	0.28	0.52	6.4	5.3	1.1	8.72	8.18	0.54	28.2	27.0	1.2
0.05	15	0.25	6.49	6.39	0.10	269	272	(3)	0.11	0.21	6.2	5.1	1.1	0.88	0.87	0.01	27.0	25.9	1.1
1.00	15	3.12	6.09	4.84	1.25	272	413	(141)	0.09	0.41	6.3	5.1	1.2	16.16	17.23	(1.07)	26.4	25.9	0.5
10 Minutes																		
0.53	5	0.57	6.60	6.72	(0.12)	269	205	64	0.12	0.28	6.3	5.1	1.2	8.66	8.85	(0.19)	28.4	27.4	1.0
0.05	10	0.21	6.41	6.11	0.30	258	213	45	0.44	0.6	6.1	5.0	1.1	0.97	0.87	0.10	27.3	26.4	0.9
1.00	10	1.83	6.35	5.14	1.21	261	251	10	0.31	0.53	6.2	5.1	1.1	16.08	16.76	(0.68)	28.5	27.9	0.6
0.53	15	1.86	6.45	5.16	1.29	246	272	(26)	0.39	0.58	6.1	5.0	1.1	8.67	8.97	(0.30)	28.6	27.6	1.0

Table 8 : Alkaline Electrolyzed Water (Nickel)

NaCl Concent. (wt.%)	Volt. (V)	Amp. (A)	pH			ORP (mV)			Free Chlorine (mg/l)	Total Chlorine (mg/l)	DO			[redacted]					
			Bef.	Aft.	Diff.	Bef.	Aft.	Diff.	Aft.	Aft.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.
5 Minutes																			
0.53	5	0.56	6.22	9.94	(3.72)	256	63	193			6.4	5.3	1.1	8.23	8.45	(0.22)	26.6	26.6	0.0
0.05	10	0.18	5.79	5.88	(0.09)	280	274	6			6.3	5.1	1.2	0.87	0.86	0.01	27.5	27.3	0.2
1.00	10	2.47	6.03	11.5	(5.47)	266	0	266			6.1	5.1	1.0	14.84	20.00	(5.16)	26.1	26.0	0.1
0.53	15	2.48	6.18	11.81	(5.63)	240	174	66			6.1	5.1	1.0	8.55	9.09	(0.54)	27.2	27.2	0.0
7.5 Minutes																			
0.05	5	0.08	5.56	6.09	(0.53)	290	231	59			6.3	5.1	1.2	0.91	0.83	0.08	26.6	26.2	0.4
1.00	5	1.05	6.40	11.42	(5.02)	228	-717	945			6.0	5.0	1.0	15.75	16.62	(0.87)	25.8	25.4	0.4
0.53	10	1.36	6.59	11.35	(4.76)	197	-478	675			6.1	5.1	1.0	8.62	8.97	(0.35)	25.8	25.4	0.4
0.53	10	1.33	6.55	11.5	(4.95)	198	-613	811			6.0	5.0	1.0	8.72	9.27	(0.55)	26.2	25.8	0.4
0.53	10	1.31	6.45	11.32	(4.87)	246	-240	486			6.3	5.1	1.2	8.49	8.98	(0.49)	26.4	26.1	0.3
0.53	10	1.3	6.37	11.31	(4.94)	239	-355	594			6.2	5.0	1.2	8.67	8.55	0.12	29.1	27.9	1.2
0.53	10	1.24	6.13	11.33	(5.20)	273	-231	504			6.4	5.2	1.2	8.72	9.16	(0.44)	28.2	27.7	0.5
0.05	15	0.25	6.49	10.51	(4.02)	269	28	241			6.2	5.1	1.1	0.88	0.92	(0.04)	27.0	26.5	0.5
1.00	15	3.12	6.09	11.57	(5.48)	272	-371	643			6.3	5.2	1.1	16.16	17.22	(1.06)	26.4	26.1	0.3
10 Minutes																			
0.53	5	0.57	6.60	10.86	(4.26)	269	-9	278			6.3	5.1	1.2	8.66	9.04	(0.38)	28.4	28.1	0.3
0.05	10	0.21	6.41	10.21	(3.80)	258	122	136			6.1	5.1	1.0	0.97	0.90	0.07	27.3	26.8	0.5
1.00	10	1.83	6.35	11.56	(5.21)	261	-807	1068			6.2	5.0	1.2	16.08	17.51	(1.43)	28.5	28.3	0.2
0.53	15	1.86	6.45	11.63	(5.18)	246	-752	998			6.1	5.1	1.0	8.67	9.26	(0.59)	28.6	28.5	0.1

Repetition 1

Table 9 : Acidic Electrolyzed Water (Aluminium Alloy)

NaCl Concent. (wt.%)	Volt. (V)	Amp. (A)	pH			ORP (mV)			Free Chlorine (mg/l)	Total Chlorine (mg/l)	DO			[redacted]					
			Bef.	Aft.	Diff.	Bef.	Aft.	Diff.	Aft.	Aft.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.
5 Minutes																			
0.53	5	0.64	5.70	5.42	0.28	406	327	79	0.15	0.61				7.74	8.42	(0.68)	25.2	24.9	0.3
0.05	10	0.19	6.10	5.82	0.28	333	348	(15)	0.05	0.40				1.18	0.96	0.22	25.0	24.7	0.3
1.00	10	2.59	5.78	4.84	0.94	349	196	153	0.13	0.28				14.22	15.46	(1.24)	24.9	24.7	0.2
0.53	15	2.44	5.77	4.73	1.04	431	61	370	0.16	0.32				8.46	8.96	(0.50)	26.5	27.5	(1.0)
7.5 Minutes																			
0.05	5	0.09	5.79	5.21	0.58	389	224	165	0.14	0.35				0.93	0.92	0.01	26.6	26.5	0.1
1.00	5	1.28	5.96	4.79	1.17	339	158	181	0.16	0.25				15.40	16.07	(0.67)	25.8	25.9	(0.1)
0.53	10	1.59	5.93	4.80	1.13	313	117	196	0.11	0.31				8.68	8.94	(0.26)	25.6	26.1	(0.5)
0.53	10	1.46	5.76	4.80	0.96	308	180	128	0.10	0.49				7.97	8.24	(0.27)	25.7	26.4	(0.7)
0.53	10	1.49	5.74	4.75	0.99	435	144	291	0.11	0.76				8.51	8.91	(0.40)	26.6	27.0	(0.4)
0.53	10	1.69	5.81	4.78	1.03	324	53	271	0.13	0.27				8.06	8.39	(0.33)	26.3	26.7	(0.4)
0.53	10	1.36	5.75	4.81	0.94	318	131	187	0.19	0.76				8.40	8.51	(0.11)	26.1	26.3	(0.2)
0.05	15	0.28	7.82	5.11	2.71	312	216	96	0.16	0.32				0.85	0.88	(0.03)	25.8	25.7	0.1
1.00	15	5.79	5.85	4.35	1.50	304	39	265	0.05	0.44				15.90	17.42	(1.52)	24.2	23.3	0.9
10 Minutes																			
0.53	5	0.75	5.74	4.81	0.93	458	80	378	0.45	0.84				8.30	8.17	0.13	28.1	28.2	(0.1)
0.05	10	0.21	5.88	5.10	0.78	363	179	184	0.22	0.77				1.04	1.06	(0.02)	27.2	27.3	(0.1)
1.00	10	3.15	5.72	4.55	1.17	309	-89	398	0.21	0.24				15.94	16.75	(0.81)	27.2	28.2	(1.0)
0.53	15	2.91	6.02	4.57	1.45	250	97	153	0.05	0.19				8.46	9.11	(0.65)	28.2	29.6	(1.4)

Table 10 : Alkaline Electrolyzed Water (Aluminium Alloy)

NaCl Concent. (wt.%)	Volt. (V)	Amp. (A)	pH			ORP (mV)			Free Chlorine (mg/l)	Total Chlorine (mg/l)	DO			[redacted] (Sm)			[redacted]		
			Bef.	Aft.	Diff.	Bef.	Aft.	Diff.	Aft.	Aft.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.
5 Minutes																			
0.53	5	0.64	5.70	10.27	(4.57)	406	92	314						7.74	7.98	(0.24)	25.2	25.0	0.2
0.05	10	0.19	6.10	6.69	(0.59)	333	258	75						1.18	0.96	0.22	25.0	24.8	0.2
1.00	10	2.59	5.78	11.49	(5.71)	349	-617	966						14.22	15.68	(1.46)	24.9	24.8	0.1
0.53	15	2.44	5.77	11.62	(5.85)	431	-629	1060						8.46	9.60	(1.14)	26.5	26.8	(0.3)
7.5 Minutes																			
0.05	5	0.09	5.79	10.47	(4.68)	389	216	173						0.93	0.92	0.01	26.6	26.5	0.1
1.00	5	1.28	5.96	11.53	(5.57)	339	-723	1062						15.40	16.91	(1.51)	25.8	25.8	0.0
0.53	10	1.59	5.93	11.74	(5.81)	313	-761	1074						8.68	9.94	(1.26)	25.6	25.8	(0.2)
0.53	10	1.46	5.76	11.51	(5.75)	308	-760	1068						7.97	9.55	(1.58)	25.7	25.8	(0.1)
0.53	10	1.49	5.74	11.72	(5.98)	435	-775	1210						8.51	9.54	(1.03)	26.6	26.8	(0.2)
0.53	10	1.69	5.81	11.60	(5.79)	324	-801	1125						8.06	9.02	(0.96)	26.3	26.4	(0.1)
0.53	10	1.36	5.75	11.45	(5.70)	318	-770	1088						8.40	9.31	(0.91)	26.1	26.2	(0.1)
0.05	15	0.28	7.82	10.99	(3.17)	312	-48	360						0.85	1.02	(0.17)	25.8	25.7	0.1
1.00	15	5.79	5.85	11.61	(5.76)	304	-822	1126						15.90	19.01	(3.11)	24.2	23.4	0.8
10 Minutes																			
0.53	5	0.75	5.74	11.66	(5.92)	458	-580	1038						8.30	9.17	(0.87)	28.1	27.9	0.2
0.05	10	0.21	5.88	10.65	(4.77)	363	-18	381						1.04	1.02	0.02	27.2	27.2	0.0
1.00	10	3.15	5.72	11.96	(6.24)	309	-757	1066						15.94	17.93	(1.99)	27.2	27.9	(0.7)
0.53	15	2.91	6.02	11.74	(5.72)	250	-709	959						8.46	10.05	(1.59)	28.2	28.0	0.2

Repetition 2

Table 11 : Acidic Electrolyzed Water (Aluminium Alloy)

NaCl Concent. (wt.%)	Volt. (V)	Amp. (A)	pH			(mV)			[redacted] (mg/l)	[redacted] (mg/l)	DO			[redacted]					
			Bef.	Aft.	Diff.	Bef.	Aft.	Diff.	Aft.	Aft.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.
5 Minutes																			
0.53	5	0.74	5.89	5.42	0.47	343	302	41	0.07	0.55				8.37	8.56	(0.19)	25.0	25.0	0.0
0.05	10	0.19	5.95	5.63	0.32	381	344	37	0.19	0.65				0.89	0.87	0.02	24.9	24.5	0.4
1.00	10	2.76	6.07	4.95	1.12	259	182	77	0.10	0.27				15.68	15.68	0.00	24.8	24.6	0.2
0.53	15	2.38	6.17	4.71	1.46	337	216	121	0.22	0.26				8.54	8.90	(0.36)	26.8	26.7	0.1
7.5 Minutes																			
0.05	5	0.09	5.88	5.88	0.00	395	255	140	0.18	0.33				0.92	0.89	0.03	26.5	26.3	0.2
1.00	5	1.26	5.98	4.66	1.32	302	127	175	0.15	0.22				15.82	16.25	(0.43)	25.8	25.8	0.0
0.53	10	1.51	5.82	4.83	0.99	328	181	147	0.14	0.34				8.31	8.71	(0.40)	25.9	26.2	(0.3)
0.53	10	1.51	5.78	4.84	0.94	315	173	142	0.15	0.65				8.30	8.69	(0.39)	25.5	26.4	(0.9)
0.53	10	1.54	5.73	4.70	1.03	327	124	203	0.12	0.37				8.46	8.55	(0.09)	26.5	26.6	(0.1)
0.53	10	1.51	5.65	4.77	0.88	344	96	248	0.20	0.35				8.31	8.54	(0.23)	26.1	26.5	(0.4)
0.53	10	1.58	5.65	5.23	0.42	308	135	173	0.20	0.36				8.56	8.74	(0.18)	25.8	26.4	(0.6)
0.05	15	0.33	6.14	4.84	1.30	367	268	99	0.20	0.50				0.91	0.94	(0.03)	24.0	23.5	0.5
1.00	15	5.23	5.66	4.47	1.19	274	82	192	0.05	0.22				16.75	17.71	(0.96)	24.9	26.5	(1.6)
10 Minutes																			
0.53	5	0.72	5.65	4.94	0.71	339	104	235	0.09	0.46				8.37	8.41	(0.04)	27.8	27.8	0.0
0.05	10	0.19	6.00	5.08	0.92	361	180	181	0.12	0.94				0.89	0.90	(0.01)	26.4	26.4	0.0
1.00	10	3.14	5.69	4.54	1.15	245	-180	425	0.13	0.31				15.86	16.65	(0.79)	28.3	29.4	(1.1)
0.53	15	2.80	5.78	4.57	1.21	265	82	183	0.05	0.38				8.42	8.91	(0.49)	28.0	28.3	(0.3)

Table 12 : Alkaline Electrolyzed Water (Aluminium Alloy)

NaCl Concent. (wt.%)	Volt. (V)	Amp. (A)	pH			(mV)			(mg/l)	(mg/l)	DO			[redacted]					
			Bef.	Aft.	Diff.	Bef.	Aft.	Diff.	Aft.	Aft.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.
5 Minutes																			
0.53	5	0.74	5.89	9.91	-4.02	343	118	225						8.37	8.09	0.28	25.0	24.5	0.5
0.05	10	0.19	5.95	7.06	-1.11	381	119	262						0.89	0.85	0.04	24.9	24.8	0.1
1.00	10	2.76	6.07	11.48	-5.41	259	120	139						15.68	15.68	0.00	24.8	24.8	0.0
0.53	15	2.38	6.17	11.83	-5.66	337	121	216						8.54	9.77	(1.23)	26.8	26.9	(0.1)
7.5 Minutes																			
0.05	5	0.09	5.88	10.37	(4.49)	395	134	261						0.92	0.82	0.10	26.5	26.3	0.2
1.00	5	1.26	5.98	11.63	(5.65)	302	-771	1073						15.82	16.42	(0.60)	25.8	26.0	(0.2)
0.53	10	1.51	5.82	11.63	(5.81)	328	-756	1084						8.31	9.08	(0.77)	25.9	26.0	(0.1)
0.53	10	1.51	5.78	11.64	(5.86)	315	-748	1063						8.30	9.03	(0.73)	25.5	25.5	0.0
0.53	10	1.54	5.73	10.34	(4.61)	327	-411	738						8.46	9.34	(0.88)	26.5	26.7	(0.2)
0.53	10	1.51	5.65	11.51	(5.86)	344	-745	1089						8.31	9.40	(1.09)	26.1	26.2	(0.1)
0.53	10	1.58	5.65	11.30	(5.65)	308	-746	1054						8.56	9.13	(0.57)	25.8	25.9	(0.1)
0.05	15	0.33	6.14	10.87	(4.73)	367	-108	475						0.91	1.05	(0.14)	24.0	24.1	(0.1)
1.00	15	5.23	5.66	11.70	(6.04)	274	-816	1090						16.75	18.61	(1.86)	24.9	24.4	0.5
10 Minutes																			
0.53	5	0.72	5.65	11.45	(5.80)	339	-501	840						8.37	9.05	(0.68)	27.8	27.7	0.1
0.05	10	0.19	6.00	10.25	(4.25)	361	-68	429						0.89	0.91	(0.02)	26.4	26.1	0.3
1.00	10	3.14	5.69	11.89	(6.20)	245	-770	1015						15.86	18.22	(2.36)	28.3	28.5	(0.2)
0.53	15	2.80	5.78	11.95	(6.17)	265	-703	968						8.42	10.14	(1.72)	28.0	28.3	(0.3)

Table 13 : Life Cycle of Electrode

Day : 1

	Anode	Cathode
Type of Material	SS	Titanium
Weight (g)	153.85	87.52

Physical & chemical properties:

Acidic

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.	Aft.	Aft.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.
9.19 Minutes																			
0.82	11.52	2.56	6.12	2.97	3.15	465	1106	(641)	14.64	14.32				10.11	14.23	(4.12)	27.5	27.9	(0.4)

Alkaline

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.	Aft.	Aft.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.
9.19 Minutes																			
0.82	11.52	2.56	6.12	11.45	(5.33)	465	(755)	290						10.11	14.65	(4.54)	27.5	27.9	(0.4)

Table 14 : Life Cycle of Electrode

Day : 2

	Anode	Cathode
Type of Material	SS	Titanium
Weight (g)	153.57	87.48

Physical & chemical properties:

Acidic

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.	Aft.	Aft.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.
9.19 Minutes																			
0.82	11.52	2.45	6.11	2.80	3.31	463	1146	(683)	14.02	14.05				10.44	14.56	(4.12)	27.8	27.9	(0.10)

Alkaline

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.	Aft.	Aft.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.
9.19 Minutes																			
0.82	11.52	2.45	6.11	11.89	(5.78)	453	(756)	303						10.44	14.67	(4.23)	27.8	28.2	(0.40)

Day : 3

Table 15 : Life Cycle of Electrode

	Anode	Cathode
Type of Material	SS	Titanium
Weight (g)	153.34	87.48

Physical & chemical properties:

Acidic

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.	Aft.	Aft.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.
9.19 Minutes																			
0.82	11.52	2.76	6.07	2.76	3.31	453	1137	(684)	13.27	13.54				10.38	14.36	(3.98)	28.3	28.5	(0.20)

Alkaline

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.	Aft.	Aft.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.
9.19 Minutes																			
0.82	11.52	2.76	6.07	11.74	(5.67)	453	(789)	336						10.38	14.47	(4.09)	28.3	28.5	(0.20)

Table 16 : Life Cycle of Electrode

Day : 4

	Anode	Cathode
Type of Material	SS	Titanium
Weight (g)	153.18	87.46

Physical & chemical properties:

Acidic

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.	Aft.	Aft.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.
9.19 Minutes																			
0.82	11.52	2.76	5.97	3.01	2.96	444	1123	(679)	12.65	12.78				10.32	13.67	(3.35)	27.5	27.9	(0.40)

Alkaline

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.	Aft.	Aft.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.
9.19 Minutes																			
0.82	11.52	2.76	5.97	11.43	-5.46	444	(765)	1209						10.32	13.89	(3.57)	27.5	27.8	(0.30)

Table 17 : Life Cycle of Electrode

Day : 5

	Anode	Cathode
Type of Material	SS	Titanium
Weight (g)	152.89	87.42

Physical & chemical properties:

Acidic

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.	Aft.	Aft.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.
9.19 Minutes																			
0.82	11.52	2.56	5.98	2.98	3.00	426	1109	(683)	11.87	12.21				10.45	14.29	(3.84)	27.6	27.9	(0.3)

Alkaline

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.	Aft.	Aft.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.
9.19 Minutes																			
0.82	11.52	2.56	5.98	11.27	(5.29)	426	(772)	346						10.45	14.34	(3.89)	27.5	27.7	(0.2)

Table 18 : Life Cycle of Electrode

Day : 6

	Anode	Cathode
Type of Material	SS	Titanium
Weight (g)	152.67	87.38

Physical & chemical properties:

Acidic

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.	Aft.	Aft.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.
9.19 Minutes																			
0.82	11.52	2.56	6.05	2.96	3.09	443	1132	(689)	11.05	12.32				10.13	14.23	(4.10)	27.5	27.6	(0.1)

Alkaline

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.	Aft.	Aft.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.
9.19 Minutes																			
0.82	11.52	2.56	6.05	11.43	(5.38)	443	(763)	320						10.13	14.54	(4.41)	27.5	27.7	(0.2)

Table 19 : Life Cycle of Electrode

Day : 7

	Anode	Cathode
Type of Material	SS	Titanium
Weight (g)	152.31	87.13

Physical & chemical properties:

Acidic

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.	Aft.	Aft.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.
9.19 Minutes																			

Alkaline

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.	Aft.	Aft.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.	Bef.	Aft.	Diff.
9.19 Minutes																			

Table 20 : Example of current effiency calculation for this work

Equation	Parameter Values	Answer
Charge transferred, Q (A/s) = Electric current, I (A) x Electrolysis time, t	I = 0.43 A t = 600 s Q = (0.43)(600)	Q = 258 (As)
Number of mol electron transferred, n (mol) = $\frac{\text{Charge transferred, Q (A/s)}}{\text{Faraday constant, F (C/mol)}}$	F = 96,485 As/mol $n = \frac{258\ As}{96485\ As/mol}$	n = 0.003 mol
Theoretical mass of chlorine produced, m = n (mol) x Molar mass (g/mol)	2Cl- = Cl2 + 2e- Molar mass Cl2 = 70.906 g/mol $m \cdot \frac{(0.003mol)(70.906\frac{g}{mol})(1molCl^2)}{(1molCl^2)(2mole\ )}$	m = 0.09 In this work, the electrolytes is 3.4L. thus the theoratical chlorine produce is mCl2=0.09/3.4L = 0.028g/L =27.88mg/L
Current density, p (A/m²) $= \frac{\text{Electrical current (A)}}{\text{Effective surface area of anode, A, }(m^2)}$	I = 0.43 A A = 0.01m2 $\therefore \frac{0.43A}{0.01m^2}$	$p = 43\ A/m^2$
Current efficiency (%) = $\frac{\text{Experimental production of total chlorine (mg)}}{\text{Theoratical production of total chlorine, (mg)}}$ x100%	Current efficiency (%) = $\frac{4.32\ mg}{27.88\ mg}$ x100%	= 16 %

Table 21 : Example of calculation for validation error for this work

Equation	Parameter Values	Answer
Experimental validation $\frac{(\text{Experimental} - \text{predicted})}{\text{predicted}} \times 100\%$	$\frac{(12.087 - 11.785)}{11.785} \times 100\%$	$= 3\%$

Table 22 : Example of calcution for corrosion rates of electrode in this work

Equation	Parameter Values	Answer
$Rc = \frac{\dot{w}}{At}$ $\dot{w}$ = weight difference (final weight - initial weight) (g) A = Surface area of electrode (cm^2) t = immersed time (h)	$Rc = \frac{0.28g}{100cm^2 * 0.15h}$	$= 0.019\ gcm^{-2}h^{-1}$