UNIVERSITI PUTRA MALAYSIA

OPTIMIZATION OF ELECTROLYZED WATER PRODUCTION FOR CLEANING APPLICATION USING RESPONSE SURFACE METHODOLOGY (RSM)

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ABSTRACT

The aim of this study was to develop proper electrolyzed technique and evaluate the characteristics of electrolysed water at optimal condition to be applied as cleaning medium in food industry. Electrolyzed water known as green cleaner is expected to help food industry in achieving hygienic environment in their factory and at the same time minimizing the cleaning cost. Acidic electrolyzed water (AcEW) and neutral electrolyzed water (NEW) have a strong bactericidal effect on various types of food borne pathogens for many types of food products and food equipment surfaces. While alkaline electrolyzed water (AlEW) has a potential as cleaning medium alternative for alkaline wash. Effect of electrolyzing parameters (electrode type, NaCl concentration, electric current and electrolysis time) on chemical and physical properties (pH, oxidation-reduction potential (ORP), total chlorine and free chlorine) of electrolyzed water (alkaline, acidic, and neutral electrolyzed water) were optimized by using Response Surface Methodology (RSM). From the RSM and Box Behnken Design (BBD), an optimal condition for AcEW is obtained at 0.1wt% NaCl concentration, 30 minutes electrolysis time and 24 V to produced 3.30 pH, 921.163mV, 0.33mg/l free chlorine and 0.37mg/l total chlorine. For AlEW, the optimized condition is at 1.0wt% NaCl concentration, 30 minutes electrolysis time and 24V in order to produce the optimum values of responses 11.37 pH values, -898.996mV, 0.21mg/l free chlorine and 0.20mg/l total chlorine. The shelf life of electrolyzed water generated from this electrolyzing unit are investigated where the electrolyzed water were stored in tight closed dark-brown glass bottles at room temperature. The chemical and physical properties of electrolyzed water are measured for 24 hours of storage. It shows reduction in pH, ORP, free chlorine where for AcEW 7.64%, 27.9% and 24.1% while for AlEW 0.27%, 76% and 10.5% respectively in

percentage of reduction. The results suggest that the electrolyzed water to be used on the same day of generation for efficient effects.

ABSTRAK

Tujuan kajian ini adalah untuk membangunkan teknik elektrolisis yang sesuai dan menilai ciri-ciri air elektrolisis pada keadaan optimum untuk digunakan sebagai medium pembersihan dalam industri makanan. Air elektrolisis yang dikenali sebagai pembersih yang selamat diharapkan dapat membantu industri makanan dalam mencapai persekitaran yang bersih di kilang mereka dan pada masa yang sama meminimumkan kos pembersihan. Air elektrolisis berasid (AcEW) dan air elektrolisis yang neutral (NEW) mempunyai kesan bakterisida yang kuat terhadap pelbagai jenis bakteria yang ada pada makanan untuk pelbagai jenis produk makanan dan permukaan peralatan makanan. Manakala, air elektrolisis alkali (AlEW) mempunyai potensi sebagai media alternatif pembersihan beralkali. Kesan parameter elektrolisis (jenis elektrod, kepekatan NaCl, arus voltan dan tempoh elektrolisis) terhadap sifat kimia dan fizikal (pH, ORP, jumlah keseluruhan klorin dan klorin bebas) air elektrolisis (air alkali, asid dan neutral elektrolisis) dioptimumkan dengan menggunakan Kaedah Surface Response Methodologi (RSM). Dari RSM dan Box Behnken Design (BBD), keadaan optimum untuk AcEW diperolehi pada 0.1% NaCl, 30 minit tempoh elektrolisis dan 24 V menghasilkan 3.30 pH, 921.163mV, 0.33mg / l klorin bebas dan 0.37mg / l jumlah keseluruhan klorin. Untuk AlEW, keadaan optimum adalah pada NaCl 1.0%, masa elektrolisis 30 minit dan 24V untuk menghasilkan nilai optimum untuk tindak balas 11.37 nilai pH, -898.996mV, 0.21mg / l klorin bebas dan 0.20mg / l jumlah keseluruhan klorin. Jangka hayat air elektrolisis yang dihasilkan daripada unit elektrolisis ini dikaji di mana air elektrolisis disimpan dalam botol kaca coklat gelap yang ditutup rapat pada suhu bilik. Sifat kimia dan fizikal air elektrolisis diukur selepas 24 jam penyimpanan. Hasilnya, ia menunjukkan pengurangan pH, ORP, klorin bebas di mana untuk AcEW 7.64%, 27.9% dan 24.1% manakala untuk AlEW 0.27%, 76%

dan 10.5% masing dalam peratusan pengurangan. Hasil kajian mencadangkan air elektrolisis diguna pada hari yang sama penghasilan untuk mendapat kesan efektif.

LIST OF ABBREVIATION

AcEW	Acidic Electrolyzed Water
AlEW	Alkaline Electrolyzed Water
NEW	Neutral Electrolyzed Water
SAEW	Slightly Acidic Electrolyzed Water
DO	Dissolved Oxygen
RSM	Response Surface Modelling
BBD	Box-Behnken Design
CCD	Central Composite Design
ORP	Oxidation Reduction Potential
FC	Free Chlorine
TC	Total Chlorine
HOCL	Hypochlorous Acid

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CHAPTER 1

INTRODUCTION

In this chapter, it gives an introduction on the importance of cleaning in food industry, problem faced in food industry involve in cleaning of food contact surfaces and the implementation of electrolyzed water as a green method cleaning in food industry. Electrolyzed water is known as sustainability and green cleaning where it properties is safer and less corrosive than chemical cleaning. Daily cleaning is needed in the food industry as cleanliness of equipment involve in food contact surfaces is important in order to produce safe food product for consumers. Negligence of cleanliness of equipment can lead to cross contamination, microbial growth and shorter lifecycles for machinery and tools.

1.1 Cleaning and sanitation in food industry

Cleaning and sanitation is very crucial in food industry where it is a measure to ensure food safety at all stages. Cleaning in term of definition is removal of any dirt while sanitation is reducing the number of microbes on the surfaces contact with foods at an acceptable level. Purpose of cleaning in food industry involve in a very wide range where it concern to reduce hazard and removal of any food contamination to avoid food poisoning and foodborne illness. Improper sanitation in food industry may cause return of food products, less profits, food wastage and other consequences that often faced by the food manufacturers.

Most of the food industries are using chemical agent on the food contact surfaces of all the equipment involved at all step of productions. Chemical used includes detergents, disinfectants and sanitizers. The process of cleaning is in sequence where first it is cleanse by detergents to remove the dirt, follow by disinfectants where it use chemicals to reduce the number of microorganism on the surface contact and last is sanitation process. In food industry, chlorine compounds, organic acids, trisodium phosphate, iodophores, and quaternary are typical sanitizer used for sanitization. The most effective is chlorine even though it is more corrosive and irritating than iodine and quaternary ammonium compounds (Hricova et al., 2008).

Sanitation that uses chemical especially chlorine, iodine and quaternary ammonium compound have it pro and cons. Higher pH of chlorine may cause skin irritation and for iodine it may discolour equipment if used at high temperature. While for quaternary ammonium compound, it is not suitable to use with some detergent and hard water. Cleaning in food industry is important because it has to eliminate food potential hazards by having a clean and sanitize food contact surfaces throughout all the process.

1.2 Problem Statement

Improper handling of food such as contaminated food by pathogenic bacteria, viruses, and parasites that lead to food borne illness is very crucial in food industry. Thus an effective cleaning system is require to increase the cleanliness of food contact surfaces. Many food industry are using chemical or detergent in their equipment sanitation process that will cause potential hazard to the consumer if not handle with care.

Thus, a proper cleaning system is needed where the food manufacturers need to make sure there is no chemical residue after final rinsing to avoid food contamination. Cost of cleaning is also an issue in food industry where the cost of commercial cleaning includes the chemical cost, utility cost and waste water treatment cost. Thus it is a factor that need to be considered by food manufacturer to stabilize their income, profit and yet the quality of food product is maintained.

1.3 Objectives of the Study

This project was completed in one year and the experimental works were performed using lab-scale electrolysing cell unit, which was fabricated in Universiti Putra Malaysia. The objectives of this project are:

i. To optimize electrolysing parameters (NaCl concentration (0.1-1.0wt %), Voltage (9, 16&24 V), electrolysis time (10, 20, 30 minutes) on chemical and physical properties (pH, oxidation-reduction potential (ORP), total residue chlorine, dissolved oxygen, electrical conductivity) of **alkaline electrolyzed water**;

ii. To optimize electrolysing parameters (NaCl concentration (0.1-1.0wt %), Voltage (9, 16&24 V), electrolysis time (10, 20, 30 minutes) on chemical and physical properties (pH, oxidation-reduction potential (ORP), total residue chlorine, dissolved oxygen, electrical conductivity) of **acidic electrolyzed water** and

iii. To optimize electrolysing parameters (NaCl concentration (0.1-1.0wt %), Voltage (9, 16&24 V), electrolysis time (10, 20, 30 minutes) on chemical and physical properties (pH, oxidation-reduction potential (ORP), total residue chlorine, dissolved oxygen, electrical conductivity) of **neutral electrolyzed water**.

1.4 Electrolyzed Water

Electrolyzed was first applied in year 1980s by Japan in medical purposes for sanitation and sterilization (Hricova et al, 2008). It was used for cleaning equipment and instrument that applied in hospital. Then electrolyzed water was further study by other countries on its efficacy as a disinfectants. As its efficacy was proved, it is starting to apply to reduce the pathogenic bacteria in agriculture, livestock management, food industry (fresh cut vegetable, meat, seafood and others) and also to food contact surfaces includes cutting board, kitchen utensils and surface of equipment in big industry (Aq, Ugiyama, & Sobe, n.d.; Hricova, Stephan, & Zweifel, 2008)

Electrolyzed water is a product of reaction between a combination of regular/tap water and small amount of salt concentration in an electrolysis cell. The process of electrolysis is separated with a diaphragm. The diaphragm can be either septum or membrane that separates the anode and cathode. Further, electrolyzed water basically generate two types of water which are acidic electrolyzed water and alkaline/based electrolyzed water. Both types of water have same function which act as sanitizer but at different value of pH. The acidic solution refer to hypochlorus acid and the alkaline solution refer to sodium hydroxide. For hypochlorous acid, its function as disinfectant as it contain chlorine that reduce the microbial activity while sodium hydroxide remove the dirt and grease on the surface of food and food contact surfaces.

In the process of electrolysis, sodium chloride dissolved in deionized water in the electrolysis chamber dissociates into negatively charged chloride (Cl-) and hydroxy (OH-) ions while sodium (Na+) and hydrogen (H+) ions are positively charged. The chloric and hydroxy radicals combine and form hypochlorous acid (HOCl). The description on electrochemistry of electrolysed water (EW) is given in Chapter 2. For cathode section, each positively charged sodium ion receives an electron and becomes metallic sodium and then combines with water molecules to form sodium hydroxide and hydrogen gas. The electrolysis of water is enhance by a bipolar membrane that separate both electrodes to produce strong acidic and alkali electrolyzed waters (Venkitanarayanan, Ezeike, & Doyle, 1999).

Now, electrolyzed is become more popular of its efficacy in cleaning system in food industries of many countries. Thus, many company involve in manufacturing these electrolyzed water machine to supply to the food industries for cleaning and research purposes. Electrolyzed is practicable because it save in costing where it only require water and salt solution, it also can produce on site, and eliminate the use of corrosive chemicals that will have negative effect to human health and to environmental. Electrolyzed water as sustainable disinfectant is important in a food industry because it is a significant step in green cleaning system (Huang, Hung, Hsu, & Huang, 2008; Rahman, Khan, & Oh, 2016). It is better to have sustainable cleaner that can replace the redundancy of cleaning product in a food industry to avoid misuse of it and to ease the handling of cleaning process.

1.5 Benefits of electrolyzed water

Electrolyzed water which generate electrolyzed reducing water (ERW) and electrolyzed oxidizing water (EOW) has its own speciality in eliminating dirt and microbial activity. Electrolyzed water is recognized as sustainable disinfectant and sanitizer. Electrolyzed water also known as environmental friendly cleaning system as it practices green concept (Hricova et al., 2008; Hsu, Lu, & Hsu, 2016; Rahman et al., 2016). It is proved as environmental friendly cleaning treatment because it require only water and dilute salt solution and no corrosive chemical is involved.

Electrolyzed water comply with the food safety regulations because it does not give harm to humans by using the adequate amount of all the parameter involved in electrolysis process. The process of producing electrolyzed water free from critical potential hazard where it does not contain any concentrated chemicals that high risk to human (Al-haq, Seo, Oshita, & Kawagoe, 2002; Hricova et al., 2008; Rahman, Ding, & Oh, 2010). The available chlorine concentration can be alter to reduce health risk to human while the efficacy of it in eliminating against microbes is maintained (Aq et al., n.d.).

Electrolyzed with strong reducing potential have the ability to remove dirt and grease from food contact surfaces items such as cutting board and all kitchen utensils (Hricova et al., 2008; Hsu et al., 2016; Izumi, 1999; Rahman et al., 2010; Rahman, Hyun, Wang, & Oh, 2012). Other than the ability of electrolyzed water provide better microbial reductions and electrolyzed water, it is also freshly produced and used immediately which require less time in preparing. Handling of electrolyzed water is simple and does not require lot of labour in the process because it does not need special handling and storage or any special transportation for locating, thus that reduce in operational costs (Hricova et al., 2008).

1.6 Structure of Thesis

In this thesis, the description of this work is arranged into five chapter. The following are on the specific explanation on each chapter involve in this research.

Chapter 1 gives a brief introduction on the electrolyzed water and its benefits toward food industry. The chapter continues with issues related to the importance of cleaning of food contact surfaces involve in food industry and objectives of the study.

Chapter 2 describes the previous studies and their findings related to the area of application of electrolyzed water in cleaning systems which involves the roles of electrolyzed water as sanitation liquid or medium and as antimicrobial agent. This chapter also explains the effects of electrolyzing parameter on physical and chemical properties and effects of physical and chemical properties on cleaning effectiveness.

Chapter 3 describes the method, material and equipment used for this research. In this chapter, at the beginning is on the method where electrolyzed water is prepared by using different set of parameters which involve NaCl concentration, voltage of power supply, electrolysis time and type of electrodes to study the effects on the oxidation reduction potential, chlorine content, dissolved oxygen and pH of the acidic and alkaline electrolyzed water. The experimental design for this work is described by the preparation of electrolyzed water and the determination of pH, oxidation reduction potential, total and free chlorine, and dissolved oxygen of electrolyzed water.

Chapter 4 presents the results analysis from Response Surface Modelling simulation to determine the optimized electrolyzed water to use in cleaning food contact surfaces in food industry. The results were from calculation and simulation were used to determine the optimize state to produce electrolyzed water with high cleaning effectiveness. In this chapter discusses the effects of electrolyzing parameter (NaCl concentration, electrolysis time, different electrode type, and voltage) on the physic-chemical properties.

Chapter 5 concludes the study and give some suggestion for future studies in the optimization of electrolyzed water with high cleaning effectiveness for food contact surfaces to avoid any cross contamination and microbial growth.

CHAPTER 2

LITERATURE REVIEW

In this chapter, it reviews the previous studies and their findings related to the area of application of electrolyzed water in cleaning systems which involves the roles of electrolyzed water as sanitation liquid or medium and as antimicrobial agent. The electrochemistry of electrolyzed water where the chemical reaction occurs at the chamber is also included in this chapter. Next, this chapter also explains the effects of electrolyzing parameter on physical and chemical properties and effects of physical and chemical properties on cleaning effectiveness. The target cleanliness on physically, microbiologically and chemically of electrolyzed water is also included in this chapter to support the benefits of electrolyzed water.

2.1 Electrolyzed Water as cleaner

According to Al-Haq et al (2005), the studies on electrolyzed water in the pre-harvest and postharvest application in food industry as sanitizer has been carried out by many countries such Japan, China and USA. The first application of electrolyzed water has been applied by Japan since 1980s in the sterilization of medical apparatus

(Hricova et al., 2008). Then, electrolyzed water was further used in the agriculture.(Al-haq et al., 2002). After gaining its popularity and proves its efficacy as sanitizer, electrolyzed water is widely use in the different area includes medical, food industry, agriculture, livestock management and other area involves in antimicrobial activity (Chyer Kim, Hung, & Brackett, 2000).

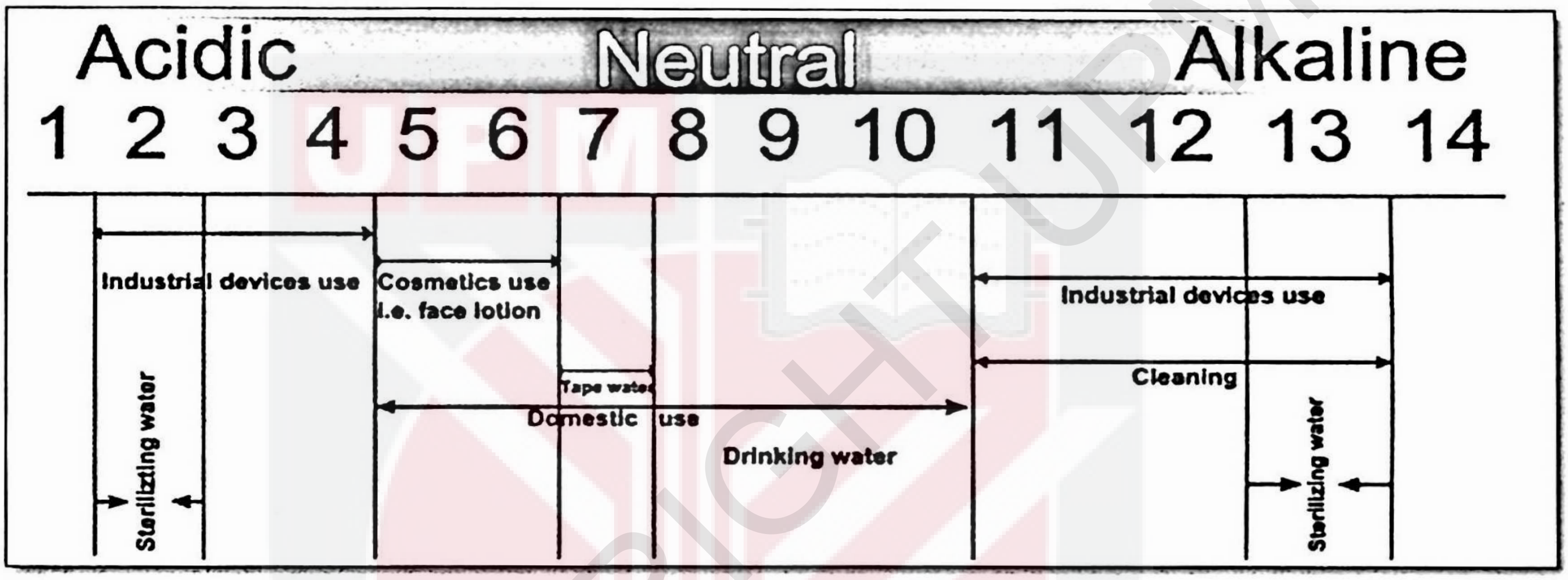


Figure 2.1: Applications of Electrolyzed water at different values of pH in various fields (Rahman et al., 2016).

From the figure above, neutral electrolyzed water (NEW) pH value is between 7 and 8. For acidic electrolyzed water (AEW), the pH values is between 2 and 3 while for (BEW) the values is more than 10 until 13. For pH values between 5.0 and 6.5 are slightly acidic electrolyzed water and for values between 8.0 and 10 are slightly basic electrolyzed water.

Electrolyzed also known as non-thermal disinfectant and sanitizer where during the process of electrolysis no heat is involve (Hricova et al., 2008). According to (Rahman et al., 2016), Ministry of Health Labor and Welfare, Japan declares that electrolyzed water is effective in treating some of the disease which includes chronic diarrhea, indigestion, hyperacidity and such disease. Electrolyzed water as antimicrobial agent is important in food safety because it removes most of the pathogenic bacteria (viruses, bacteria, fungi and spores) that can cause risk to human health (Hsu, Hsia, & Hsu, 2015; Rahman et al., 2016).

Electrolyzed water is formed by the combination of electrolyzing tap or regular water and small amount of salt solution of NaCl (Chyer Kim et al., 2000). Electrolyzed also can be produced by addition of table salt which act as a singular chemical additive (Rahman et al., 2016). It is been proved that electrolyzed water can work more efficient than solution of water and chlorine in sanitation of poultry and fresh vegetables, cutting boards and other utensils involve (Al haq et al., 2005). According to (Hricova et al., 2008), electrolyzed technology is applicable in sanitization of equipment or eliminating microbial activity of certain food products.

2.2 Electrolyzed water as antimicrobial agent

Electrolyzed Water has the bactericidal effect. The Hypochlorous Acid solution in the electrolyzed water have the ability to against various strains of bacteria due to the combined action of hydrogen ion concentration, oxidation-reduction-potential reactions and dissolved chlorine. The inactivation of microbes defence mechanism of a cell membrane is by oxidation reduction potential reactions where it first damage the outer and inner membrane of the cell. Thus, Hypoclorous Acid solution can then penetrate the cell and oxidize it.

Free Available Chlorine is formed when Hypochlorous Acid, HOCl, which is electrically neutral and Hypochlorite Ions, OCl^-, which electrically negative are bound together. This formation results in disinfection and both substances have very distinctive behaviour.

For pathogenic microorganisms, the cell wall is negatively charged thus means that the negatively charged Hypochlorite Ion (OCL-) can only penetrate it by the neutral Hypochlorous Acid (HOCL), rather than HOCL itself. HOCL itself can penetrate slime layers, cell walls and protective layers of microorganisms and effectively kills pathogens as a result. By Oxidation Reduction Potential reactions, it ease the penetration of cell membranes which results the dead of microorganisms or suffer from reproductive failures

2.3 Electrochemistry of EW.

The formation of electrolyzed water produce two types of electrolyzed water which are electrolyzed reduced water (ERW) or basic electrolyzed water (BEW) as the alkaline solution and electrolyzed oxidizing water (EOW) also called acidic electrolyzed water (AEW) (Rahman et al., 2016).

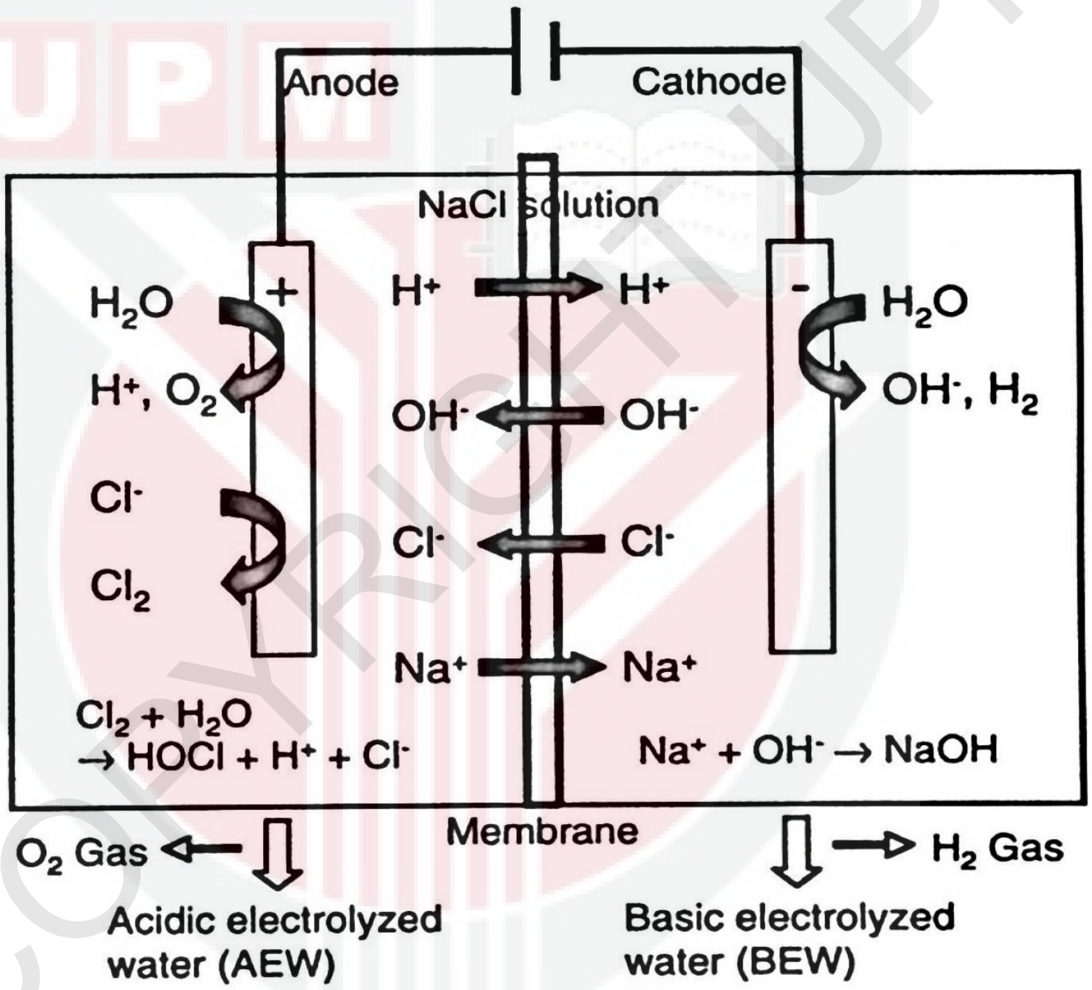


Figure 2.2: Schematic of electrolyzed water generation (Hricova et al., 2008)

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

$$2H_2O \rightarrow 4H^+ + O_2 \uparrow + 4e^-$$ Equation 2.3.1

$$2NaCl \rightarrow Cl_2 + 2e^- + 2Na^+$$ Equation 2.3.2

$$Cl_2 + H_2O \rightarrow HCl + HOCl$$ Equation 2.3.3

While the chemical reaction at the cathode reaction are:

$$2H_2O + 2e^- \rightarrow 2OH^- + H_2 \uparrow$$ Equation 2.3.4

$$2NaCl + 2OH^- \rightarrow 2NaOH + Cl^-$$ Equation 2.3.5

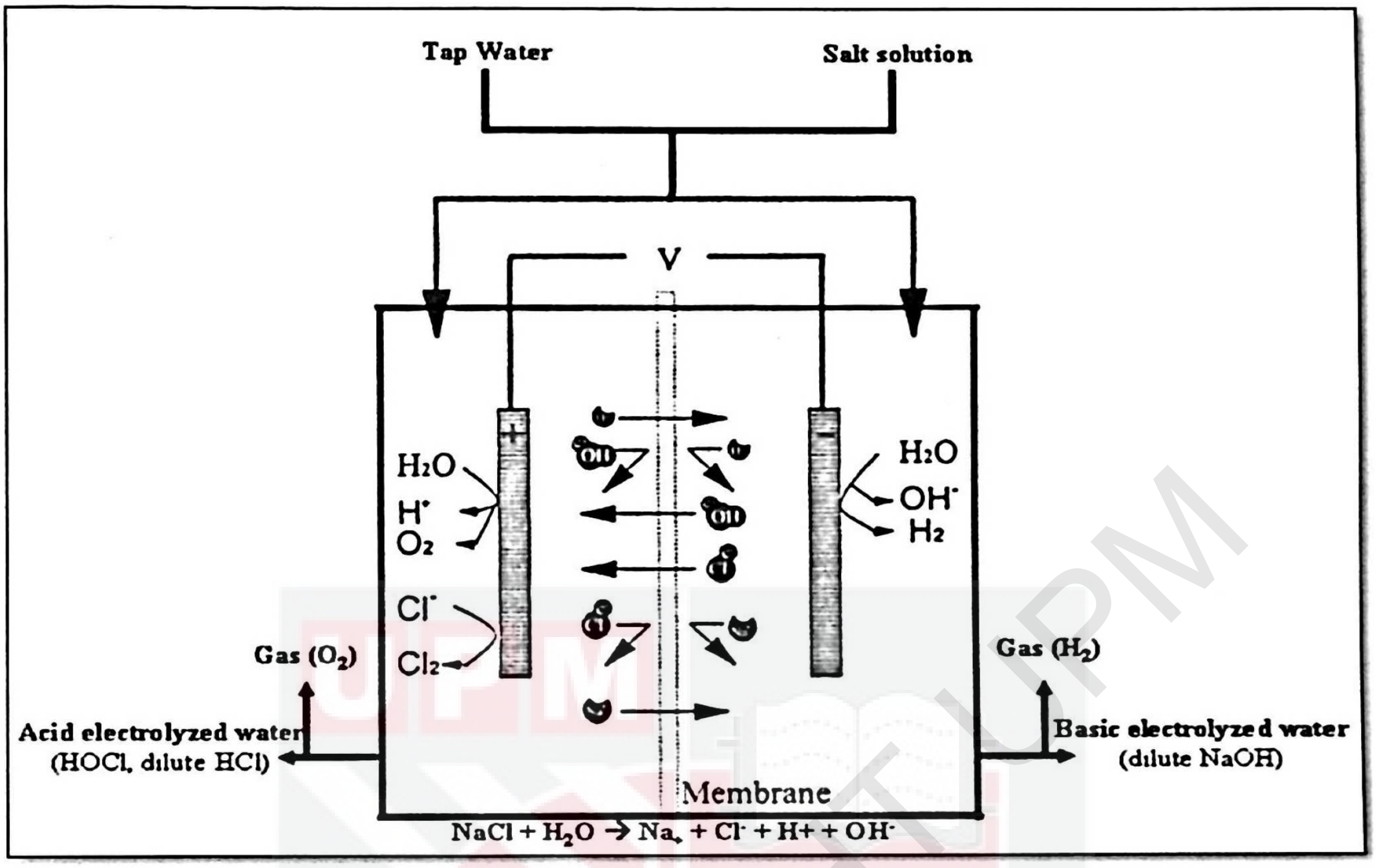


Figure 2.3: Schematic diagram of electrolyzed water generator and resulting compounds (Aq, Ugiyama, & Sobe, n.d.2005).

From the figure above, acidic electrolyzed water is obtained at anode chamber and basic electrolyzed water obtained from cathode chamber through an external power supply and separated by membrane or diaphragm (Rahman et al., 2016).

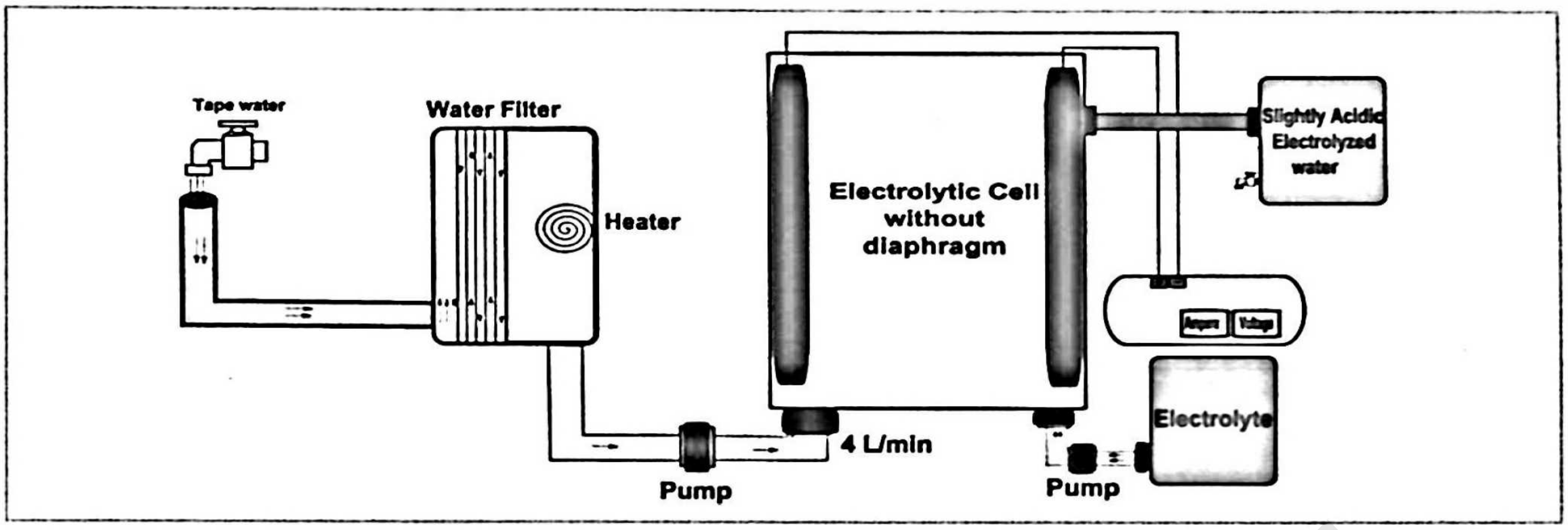


Figure 2.4: –Schematic illustration showing the generation of NEW and SAEW using an electrolytic cell without diaphragm. NEW (pH 7 to 8 and ORP 750 to 900 mV) is produced in the electrolytic cell without diaphragm using electrolytes NaCl or HCl, whereas SAEW (pH 4.5 to 6.5 and ORP approximately 900 mV) is produced from electrolyte HCl alone or in combination with NaCl in the electrolytic cell without diaphragm (Rahman et al., 2016).

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

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

2.3.1 Effect of electrolysis time and voltage

According to Hsu et al., (2015), the chlorine concentration and electric current is increasing by raising the voltage from 6V to 10V.When the electrolysis time is prolonged, there is more time interval for the production of chlorine. The pH of electrolyzed water is important in order to form various chlorine species (Rahman et al., 2016). In HOCL form when the pH value is between 5.0 to 6.5, chlorine have 80 times greater sanitizing power than –OCL (Cao, Zhu, Shi, Wang, & Li, 2009).

Enterobacteraerogenes and *S. aureus* on surface of glass, stainless, steel, glazed ceramic tile, unglazed ceramic tile and vitreous china surfaces is reduced by electrolyzed oxidizing water with pH of 2.53, ORP of 1178mV and chlorine of 53mg/l (Huang et al., 2008).

Value of pH from 2.6 to 7.0 and amount of free chlorine exert 2mg/l is shown to be effective in eliminating the organisms (Rahman et al., 2016). For electrode material, the non-active electrode surface acts only as an electron sink and has no interaction with OH-. However, in an active electrode the OH- favourably interacts with the electrode surface, resulting in the transformation into a higher oxide surface and electrode materials affected the efficiency of chlorine generation (Jeong, Kim, & Yoon, 2009).

2.3.3 Effect of NaCl concentration

According to Venkitanarayanan, Ezeike, & Doyle (1999), electrolyzed water at 35 or 45 °C, *E.coli O157:H7, S. enteritidis, and L. monocytogenes* were more rapidly inactivated than at 4 or 23°C. For 2 minutes of exposure to electrolyzed oxidizing water, the populations of E. coli O157:H7 and L. monocytogenes in the treated samples is decreasing rapidly. Electrolyzed oxidizing water at 45°C for I minutes of exposures can killed completely E. coli O157:H7 by a reduction of approximately 8.0 log CFU/ml while for S. enteritidis and L. monocytogenes reduced by approximately 7.0 log CFU/ml.

The chlorine concentration values is positively influenced by the concentration of electrolyte but not on the types of electrolyte (Rahman et al., 2016). High effectiveness of sanitizer properties of EW is at increased electrolyte concentration

(Forghani et al., 2015). This may cause by high concentration of electrolyte increase the conductivity and result in increasing chlorine production.

2.3.4 Types of electrodes

The selection of electrode material is also important in generating chlorine concentration where the order of electrode materials arranged in terms of the production of active chlorine was found to be as follows: Ti/IrO2> Ti/RuO2> Ti/Pt–IrO2> BDD > Pt (Rahman et al., 2016).While according to Hsu et al., (2015), pairing of titanium as anode and cathodes give a minimum production chlorine in the electrolysis process. This is probably because titanium have low electrical conductivity. But the production of chlorine increase when the anode chamber is replaced with platinum-plated titanium.

2.4 On target Cleanliness

2.4.1 Physically

Physically clean is defined as the surface appears clean, but chemical residues, often deliberately left to achieve a particular desired effect, may have been allowed to remain. Disinfection of the surface has not been considered. The probability of corrosion using electrolyzed water for sanitizing on the surface of equipment is very low (Rahman et al., 2010). Electrolyzed water has shown its efficacy in removing dirt and grease on food contact surfaces which are cutting board, kitchen utensils and other equipment that in contact with food throughout the process (Hricova et al., 2008; Izumi, 1999; Park et al., 2002; Rahman et al., 2010, 2016).

2.4.2 Microbiologically

Microbiologically clean is defined as the degree of microbiological contamination remaining on the surface, and may range from plant that has been 'disinfected' – that is, the number of bacteria on the surface of the equipment has been reduced to a level consistent with acceptable quality control and hygienic standards – to surfaces rendered totally sterile, as is essential in ultra-high-temperature (UHT) and similar aseptic operations. Electrolyzed water has strong bactericidal effect on *Listeria monocytogenes, E. coli O157:H7, S. Enteritidis, C. jejuni,* and *Bacillus cereus* because it contains hypochlorous acid and has a high oxidation reduction potential thus can penetrate the layer of microbial (Park, Hung, & Kim, 2002). EO water is highly effective in killing E. coli O157:H7, S. enteritidis, and L. monocytogenes, indicating its potential application for decontamination of food and food contact surfaces (Venkitanarayanan et al., 1999). The physiochemical characteristic that have in electrolyzed water is shown to greatly affect the antimicrobial activity (Rahman et al., 2012).

Enterobacteraerogenes and *S. aureus* on surface of glass, stainless, steel, glazed ceramic tile, unglazed ceramic tile and vitreous china surfaces is reduced by electrolyzed oxidizing water with pH of 2.53, ORP of 1178mV and chlorine of 53mg/l (Huang et al., 2008). Value of pH from 2.6 to 7.0 and amount of free chlorine exert 2mg/l is shown to be effective in eliminating the organisms (Rahman et al., 2016). For electrode material, the non-active electrode surface acts only as an electron sink and has no interaction with OH-. However, in an active electrode the OH- favourably interacts with the electrode surface, resulting in the transformation into a higher oxide surface and electrode materials affected the efficiency of chlorine generation (Jeong, Kim, & Yoon, 2009).

Electrolyzed water is the only solution that reduce the spores after 60s of treatment by 0.8 log10 CFU/ml reduction (Chyer Kim et al., 2000). At 50 °C, acidic electrolyzed water have the ability to enhance its bactericidal activity to inactivate aerobic bacteria (Xie, Sun, Pan, & Zhao, 2012). Oxidation reduction potential (ORP) reactions at the cell membrane have the ability to damage the outer and inner membrane to eliminate the microbes' defense system (Issa-zacharia, Kamitani, Miwa, Muhimbula, & Iwasaki, 2011).

2.4.3 Chemically

Chemically clean is defined as the surface is rendered totally free from any trace of chemical residues. Electrolyzed is produced by a simple electrolysis where it does not involve any added chemicals except NaCl, KCl or $MgCl_2$ (Aq et al., 2005). Special formulated chemical is commonly used in food industry to clean food processing machine and any food contact surface. But, these chemical have side effect and may cause chemical contamination on food product and it is high risk for consumer if chemical residue is remained on the surface after final rinse. Thus, electrolyzed water is used to replace the previous cleaning solutions where electrolyzed water at pH of 2.1, ORP of 1150mV and free chlorine of 8 mg/L. (Huang et al., 2008). Chemical cleaning requires minimum concentrations of sanitizers during final rinse because it could cause toxic but as for electrolyzed water, it is safer if the final rinse is not done properly as it is less corrosive compared to chemical cleaning and its shelf life is reduce along with time where it acidity or alkalinity decrease along with time.

2.5 Conclusion

Cleaning and sanitation is very crucial in food industry where it is a measure to ensure food safety at all stages. Electrolyzed water as sustainable disinfectant is important in a food industry because it is a significant step in green cleaning system. Different electrolyzing parameters (NaCl concentration, Voltage, Electrolysis time and type of electrode) are studied. This chapter has reviewed some of the studies performed by several previous researchers related to electrolyzed water production. This provides a better understanding of the lab scale electrolyzing unit that is to be used in this work.

CHAPTER 3

METHODOLOGY

For this study, the optimization of electrolyzed water is by manipulating parameters on physical and chemical properties (type of electrodes, NaCl concentration, electrolysis time and voltage) that will affect electrolyzing parameter (ph, ORP, free chlorine and total chlorine) on acidic, alkali and neutral electrolyzed water. The experiment were conducted by manipulating parameters, which are NaCl concentration (0.1-1.0wt %), voltage (9-16 V), electrolysis time (10, 20, 30 minutes) and types of electrode (Titanium, Titanium 920, Stainless Steel 304 and Silver).

3.1 Experimental Set-up

The production of electrolyzed water is first by preparing the salt solution. There are 3 types of concentration used (0.1, 0.5 and 1.0 wt. %). The concentration of salt solution is determine by the ratio of distilled water used. Then, the salt solution is pour into the ioniser and to start the electrolysis process the DC power supply is connected. In this electrolysis process, AcEW and AlEW is generated in 2 chamber set-up which anode and cathode is separated by membrane that allow ion exchange. AcEW and AlEW are collected at anode and cathode respectively. For NEW, it is generated using 1 chamber where the membrane is dissembled during electrolysis process. In this work, Titanium is used as anode and different electrode type (Stainless Steel, Silver and Titanium 920) are used as cathode.

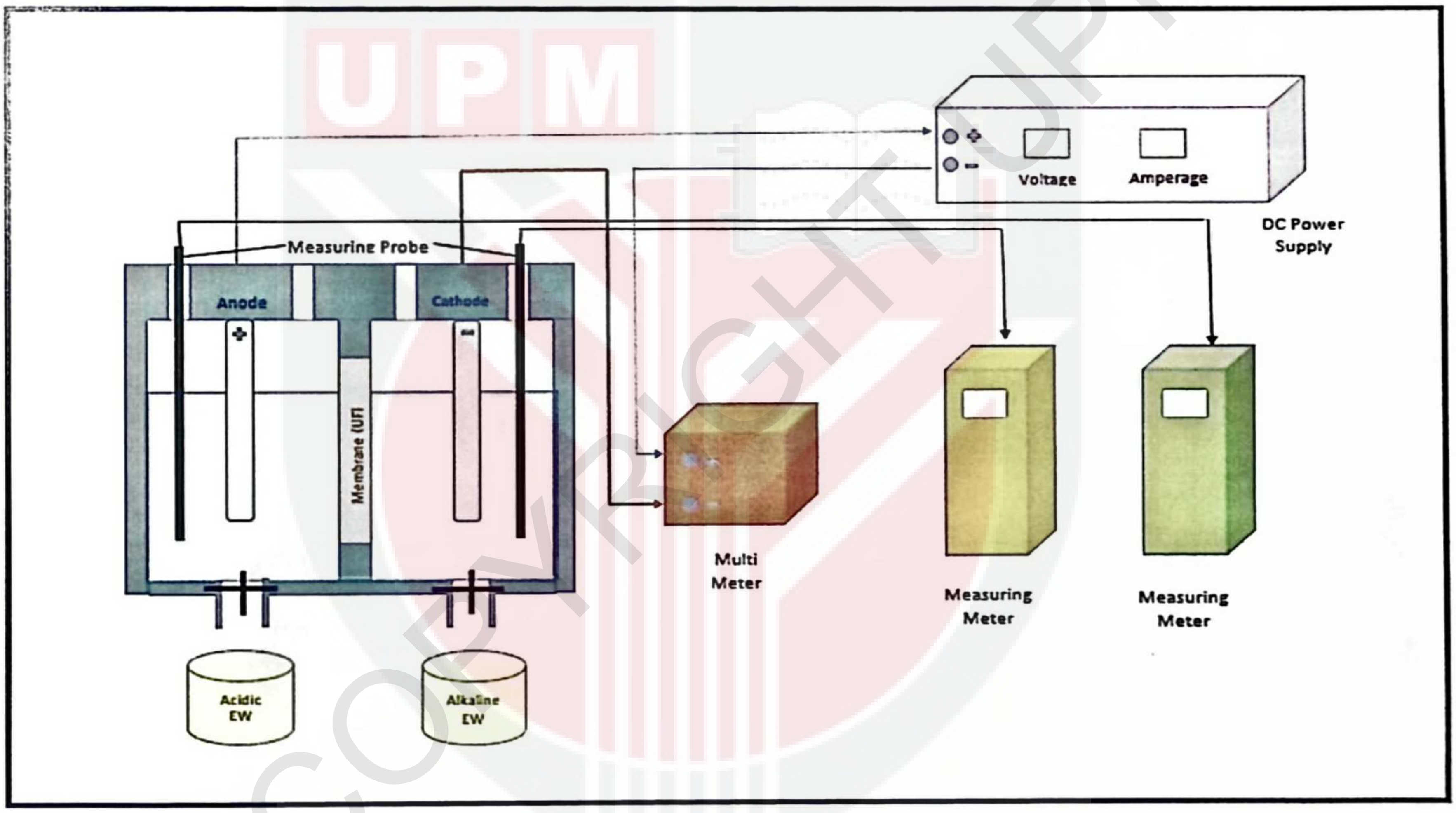


Figure 3.1 Schematic diagram of the lab-scale electrolyzing unit

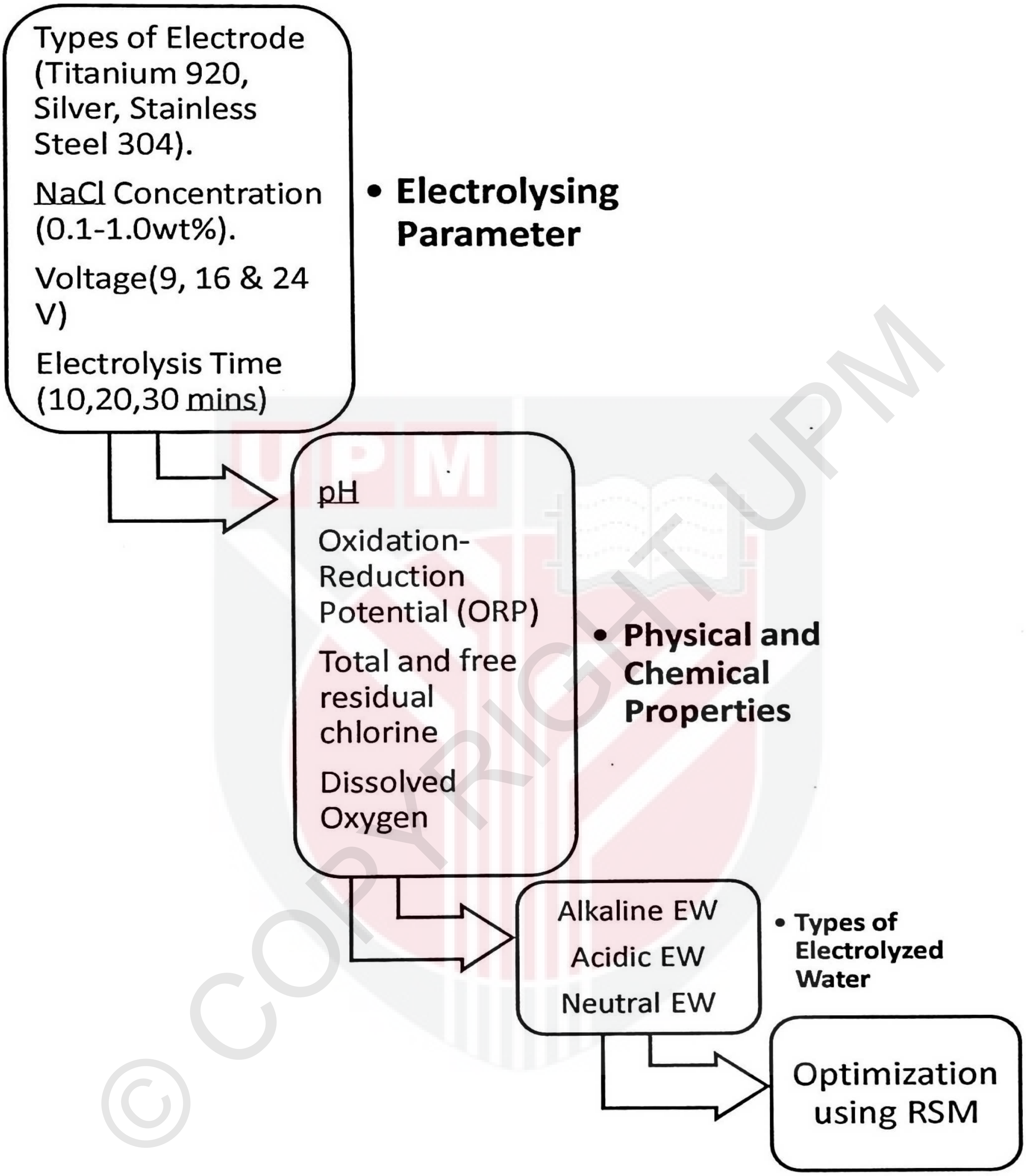


Figure 3.2: Flow chart summary of the whole experiment

3.2 Materials and Chemicals

3.2.1 Material

The selection of electrode is based on its properties of electrical conductivity, corrosiveness and current efficiency. Stainless steel 304 can experience severe corrosion when exposed to salt while titanium have good resistance to corrosion and says that it is in excellent resistance to corrosion in seawater. For silver electrode, it has the highest electrical and thermal conductivity for any material. Titanium 999 will stay at anode, while Titanium 920, Stainless Steel 304 and Silver will alternates simultaneously for this experiments.

Different electrode types is used to study the efficiency on the physical and chemical properties of the electrolyzed water. Titanium 999 (10 x 10 cm) is set as anode and Titanium 920 (10 x 10 cm), Silver (10 x 10 cm), Stainless Steel 304 (10 x 10 cm) from Good Fellow Cambridge Limited, Huntingdon, England. The electrodes is set alternately at cathode to see the different effectiveness on electrolyzed water produced.

3.2.2 Chemical used in this study

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

$$\frac{x(g)}{1000(ml)} = \%\, of\ NaCl$$

3.2.3 Type of solvents used

In order to get the uniformity of solvents, distilled water is used as the solvents to dissolve the salt, sodium chloride (NaCl) to three different concentrations (0.1, 0.5 and 1.0wt%).

3.3 Type of instruments used

Figure 3.3: Lab-scale electrolyzing unit

From the figure above, the electrolyzed water is produced using a Lab-scale electrolyzing unit. A Lab-scale electrolyzing unit is used because it can manipulate many parameters than the commercialized machine for electrolyzed water. The fabricated ioniser can manipulate voltage, electrolyte concentration, time for electrolysis and types of electrodes. Based on commercialized AEW generators, there are of 3 main types which the first type machines automatically adjust voltage and amperage but fix the brine flow rate. The second type is manipulating the amperage and voltage while for the third type is manipulate the chlorine concentration level (Rahman et al., 2016).

3.3. 1 Determination of pH

Figure 3.4: AP85 Portable Waterproof pH/ conductivity meter

Based on previous study, the range of pH for acid is between 2.4 and 2.7. For alkali solution the range of pH is between 9 and 11 while for neutral solution the pH is range from 6.5 to 7.5. For this experiment, the initial pH is taken at both chamber anode and cathode after the solution of salt is done as a control point. After the electrolysis is done, the value of pH of both side is taken by using pH probe and recorded the data. For this electrolysis process, the strong acid electrolyzed water is rarely show adverse effect to human skin because it losses acidity immediately without supply of hydrogen ion thus it is consider safe. For pH is measured with pH/mV/ISE meter with pH electrode from the Fisher Scientific, USA.

3.3.2 Determination of Oxidation-Reduction Potential (ORP).

Figure 3.5: PT-380 Hand-held pH/ORP/Temperature Meter

For the oxidation reduction potential (ORP), the normal range is between +900 to -400 mV for acidic and alkaline solution. For this study, a higher oxidation reduction potential value is required. Because in previous study, killing of bacteria is not based on chlorine only but a higher ORPs is required because it provides single measurement that have the total oxidation capability (Kim, Hung, & Brackett, 2000). Thus, the reading of oxidation reduction potential is taken at both sides before the electrolysis process to indicate as the set point. The reading of ORPs is taken by inserting the probe into the acidic and alkaline solution. Then, the reading ia taken after the electrolysis process is done and the value was recorded for every test of experiments. It is measures in millivolts using pH/mV/ISE meter equipped with redox electrode from Boeco, Germany.

3.3.3 Determination of Total and free residual chlorine.

Figure 3.6: Photometer PF-3 Macherey Nagel

For free chlorine, the process is by the reaction of chlorine with the water to form hypochlorous acid and hypochlorite ion. After this chlorine begins to react with the contaminants, it is called as combined chlorine. For total chlorine, it is the combination of free chlorine and combined chlorine. To make sure an effective sanitizing process, the value of free chlorine should be higher than combined chlorine. The values of free chlorine and total chlorine is measured in mg/l.

For this experiments, the value of chlorine is taken before the electrolysis process start. After the electrolysis process is done, the value for both free and total chlorine is recorded. The process for free chlorine measurement is first by taking 5 ml sample into a closed test tube. Then the sample is added with 1 spoon of Cl_2-1 in powder form and shake for 20 seconds. After that, the solution is let rest for 1 minutes for the reaction time. Then, the closed tube is placed in the chlorine meter and the reading was taken and recoded for every experiments.

For the total chlorine test, a 5 ml sample is taken into closed test tube and added with 1 spoon of Cl_2-1 in powder form. Then the sample is shake to 20 seconds for the mixture to blend completely. After that, 3 drop of Cl_2-2 is added to the solution and shake again for 20 seconds. After that the solution is let rest for 3 minutes and placed into the chlorine meter to take and record the reading for each experiments. It is measured using Photometer from Macherey-Nagel, Germany.

3.3.4 Determination of Dissolved Oxygen (DO).

Figure 3.7: HI 9147 Dissolved Oxygen Meter

Dissolved Oxygen is the amount of gaseous oxygen (O_2) dissolved in the water and oxygen dissolves easier in cooler water than warmer water. The concentration of dissolved oxygen in water is expressed in parts per million (ppm). Dissolved oxygen levels is important for measurement of water quality. In electrolysis process, the process creates the oxygen molecules from the water molecule itself. There is no limitation and higher value of dissolved oxygen can be achieved. For this study, the value of dissolved oxygen is taken before the electrolysis process. After the electrolyzed water is produced, the sample at both alkali and acid solution is taken and insert with dissolved oxygen meter. The reading of dissolved oxygen is recorded for every test. It is measures using an oxygen meter from Hanna Instruments, USA.

3.4 Response Surface Methodology (RSM)

Response Surface Methodology (RSM) is an experimental design method for experimental process optimization. It is based on statistical and mathematical experimental design method. The objective of using RSM is to simultaneously optimize the levels of these manipulating factors to gain the best performance of electrolyzed water (Bezerra, Santelli, Oliveira, Villar, & Escaleira, 2008). RSM is use to optimize the electrolyzing parameter to yield the peak performance of electrolyzed water in cleaning application. It is to evaluate the interaction and relationship on effect of variables and obtained response surfaces to obtain an optimum condition. The effects of experimental factors which are NaCl concentration (0.1-1.0wt %), Voltage (9, 16&24 V) and electrolysis time (10, 20, 30 minutes) is investigated using Box-Behnken design (BBD) because of its advantages on minor experimental deviations and high reliability. RSM is an efficient tools in optimizing experimental conditions to maximizes various responses (Liyana-Pathirana & Shahidi, 2005).

Table 3.1: Box-Behnken design experiment factors and levels.

Code	Factor	Level		
		-1	**0**	**1**
X_1	NaCl Concentration	0.1wt%	0.5wt%	1.0wt%
X_2	Electrolysis time	10 mins	20 mins	30 mins
X_3	Voltage	9V	16V	24V

3.5 Conclusion

The work for this study is divided into two main parts. In the first part is the production of electrolyzed water by using lab scale electrolyzing unit on different electrolyzing parameter (NaCl concentration (0.1-1.0wt %), Voltage (9, 16&24 V), electrolysis time (10, 20, 30 minutes) to obtain the result for pH, ORP, free chlorine and total chlorine. In the second part, the results obtained for pH, ORP, free chlorine and total chlorine from the lab work were optimized by using Response Surface Methodology and Box-Behnken Design to obtain the optimal condition of electrolyzed water.

CHAPTER 4

RESULTS AND DISCUSSION

In this chapter, the results analysis and discussion on the effect of different electrolyzing parameters (NaCl concentration, electrolysis time, electrode type, and voltage) on the physico-chemical properties (pH, Oxidation-Reduction Potential and Chlorine Content) of (alkaline, acidic and neutral) electrolyzed water are presented. Acidic electrolyzed water (AcEW) and neutral electrolyzed water (NEW) can be used as sanitiser or acidic wash in cleaning as it has antimicrobial activity properties. While Alkaline electrolyzed water (AlEW) can be used as replacement for alkaline wash in cleaning. Response Surface methodology (RSM) were applied to evaluate the effect of three independent variables (NaCl, electrolyzing time, voltage) to predict the optimized electrolyzed water to use in cleaning food contact surfaces in food industry. The results from RSM were used to determine the optimized condition for electrolyzing parameter to produce electrolyzed water with high cleaning effectiveness. Validation was done using the expected result from RSM and the results is compared with the empirical data. This chapter also discuss and compared the validation of optimization of electrolyzed water with experimental results.

4.1 Effects of NaCl concentration and voltage on the physico-chemical properties.

Increasing NaCl concentration increased the production of chlorine in electrolyzed water (Hsu, 2005). The NaCl concentration used in this work are 0.1% (4g), 0.5 % (20g) and 1.0% (40g) that is diluted with distilled water. Three types of electrodes (stainless steel, silver, Titanium 920) are used for the electrolysis process gives different effect on pH, Oxidation-Reduction Potential (ORP), free chlorine and total chlorine. During two chamber electrolysis process, AcEW can be collected at anode and AlEW can be collected at cathode. While, one chamber electrolysis process will produce only NEW. In this work, Titanium 999 is fixed as cathode. Table 4.1 and Table 4.2 shows results for 2 chamber electrolysis, Stainless Steel as anode electrode, 20 minutes electrolyzing time. For AcEW (Table 4.2), as the concentration of NaCl increased, the pH and ORP reduced. While the free and total chlorine increased. Increasing the concentration from 0.1% to 0.5% has no significant effect. A good AcEW with high antimicrobial activity has low pH, high chlorine content and high ORP. Contrary to the expected result, the ORP decreased as we increased the NaCl concentration. For AcEW, the pH, free chlorine and total chlorine increased when the concentration is at 0.5% (20g) and at high voltage (24V). However for AcEW, ORP is decreasing probably because NaCl concentration does give any significant effects to ORP. A good AlEW which has a cleaner characteristics has high pH, low ORP value (negative values). Usually AlEW does not hava nay chlorine content. For AlEW, Table 4.2 shows the pH, increased when the NaCl concentration is increased to 0.5wt%. Then reduced when increased to 1.0wt%. While ORP gradually decreased when the NaCl concentration increased. In this work, AlEW contains chlorine.

Increasing the NaCl concentration, reduced the chlorine content. The pattern for both Silver and Titanium 920 also shows the same pattern at both chamber anode and cathode. Replacing anode with Silver and Titanium shows similar pattern on physical and chemical properties of electrolyzed water (AlEW, AcEW and NEW).

Increasing the electrical voltage, reduced the pH value and increased the ORP, free and total chlorine content for AcEW as shown in Table 4.3 to 4.5. As the electrical potential increase, the current flow also increase where electric potential is the main driving force of the electrolysis system to the production of chlorine (Hsu et al., 2017). While for AlEW, from the Table 4.6 to 4.8 it shows that as the electrical voltage increased, the value for pH, ORP, free and total chlorine also increased.

In this work, for 1 chamber electrolysis, NEW does not show any significant result thus NEW is not critically discussed however the result for NEW is attached in the appendix.

Table 4.1: Effect of different electrolyzing parameters on physico-chemical of AcEW for stainless steel as anode at 24V for 20 minutes.

NaCl concentration (%)	**pH**	**ORP (mV)**	**Free chlorine (mg/l)**	**Total chlorine (mg/l)**
		20 minutes		
0.1	3.49	713	0.31	0.34
0.5	3.12	474	0.25	0.31
1.0	3.04	407	0.34	0.36

Table 4.2: Effect of different electrolyzing parameters on physico-chemical of AlEW for stainless steel as anode at 24V for 20 minutes.

NaCl concentration (%)	pH	ORP (mV)	Free chlorine (mg/l)	Total chlorine (mg/l)
		20 minutes		
0.1	10.69	-70	0.20	0.37
0.5	11.25	-617	0.14	0.23
1.0	10.23	-711	0.19	0.23

4.2 Effects of electrolysis time on the physic-chemical properties.

The concentration of chlorine is significantly increase along with the electrolysis time (Hsu et al., 2016). For this study, different electrolysis time are used (10 minutes, 20 minutes and 30 minutes). Effect of electrolysis time is most significant on the production of chlorine in electrolyzed water where the chloride is converted to chlorine after undergo electrolysis process for a certain time interval. The trends for the production of chlorine is observed from the table result below for electrode Stainless Steel at 10, 20 and 30 minutes for AcEW (Table 4.3-4.5) and AlEW (Table 4.6-4.8).

Table 4.3: Free and Total Chlorine Content for AcEW Stainless Steel, 10 minutes.

NaCl Concentration (%)	Voltage (V)	Free Chlorine (mg/l)	Total Chlorine (mg/l)
0.1	9	<0.05	0.06
0.1	16	0.05	0.07
0.1	24	0.07	0.10
0.5	9	0.10	0.16
0.5	16	0.23	0.26
0.5	24	0.15	0.18
1.0	9	0.19	0.23
1.0	16	0.22	0.24
1.0	24	0.23	0.25

Table 4.4: Free and Total Chlorine Content for AcEW Stainless Steel, 20 minutes.

NaCl Concentration (%)	Voltage (V)	Free Chlorine (mg/l)	Total Chlorine (mg/l)
0.1	9	0.22	0.23
0.1	16	0.24	0.28
0.1	24	0.31	0.34
0.5	9	0.18	0.31
0.5	16	0.30	0.36
0.5	24	0.25	0.31
1.0	9	0.28	0.36
1.0	16	0.30	0.33
1.0	24	0.34	0.36

Table 4.5: Free and Total Chlorine Content for AcEW Stainless Steel, 30 minutes.

NaCl Concentration (%)	Voltage (V)	Free Chlorine (mg/l)	Total Chlorine (mg/l)
0.1	9	0.25	0.29
0.1	16	0.36	0.37
0.1	24	0.29	0.38
0.5	9	0.06	0.10
0.5	16	0.16	0.21
0.5	24	0.19	0.25
1.0	9	0.23	0.26
1.0	16	0.22	0.25
1.0	24	0.27	0.37

Table 4.6: Free and Total Chlorine Content for AlEW Stainless Steel, 10 minutes.

NaCl Concentration (%)	Voltage (V)	Free Chlorine (mg/l)	Total Chlorine (mg/l)
0.1	9	0.05	0.07
0.1	16	0.05	0.06
0.1	24	0.05	0.10
0.5	9	0.07	0.08
0.5	16	0.08	0.10
0.5	24	0.09	0.12
1.0	9	0.10	0.14
1.0	16	0.11	0.15
1.0	24	0.10	0.14

Table 4.7: Free and Total Chlorine Content for AlEW Stainless Steel, 20 minutes.

NaCl Concentration (%)	Voltage (V)	Free Chlorine (mg/l)	Total Chlorine (mg/l)
0.1	9	0.08	0.12
0.1	16	0.07	0.16
0.1	24	0.20	0.37
0.5	9	0.08	0.19
0.5	16	0.11	0.20
0.5	24	0.14	0.23
1.0	9	0.15	0.21
1.0	16	0.18	0.20
1.0	24	0.19	0.23

Table 4.8: Free and Total Chlorine Content for AlEW Stainless Steel, 30 minutes.

NaCl Concentration (%)	Voltage (V)	Free Chlorine (mg/l)	Total Chlorine (mg/l)
0.1	9	0.05	0.05
0.1	16	0.05	0.05
0.1	24	0.06	0.08
0.5	9	0.09	0.07
0.5	16	0.11	0.14
0.5	24	0.18	0.20
1.0	9	0.20	0.21
1.0	16	0.16	0.22
1.0	24	0.19	0.27

From the Table 4.3 to 4.5 for electrode Stainless Steel at 10, 20 and 30 minutes above, it shown that as electrolysis time increased the production of free chlorine and total chlorine also increased. For example, for AcEW, at 24 V, 1.0wt% NaCl, when electrolysing time is increased from 10 minutes to 30 minutes, the chlorine content (free and total chlorine) increased. For 10 minutes, the free and total chlorine are 0.23 mg/L and 0.25 mg/L respectively. While at 30 minutes, the free and total chlorine are 0.27 and 0.37 mg/L respectively. From the result, it support claim by Hsu et al., () that electrolysis time gives time interval for the chlorine to be generated and being built in electrolyzed water. But increasing in electrolysis time does not give any significant effect on DO (dissolved oxygen) and temperature of EW.

4.3 Effects of different electrode types on the physico-chemical properties.

There are many factors need to be considered in selecting of suitable electrode material type in enhancing the performance of electrolyzed water produced. An electrode should be relatively inexpensive for industrial use especially Small and Medium Enterprise and have the ability to resists to corrosion, erosion, catalyse the electrode reaction and have high electrical conductivity. In this study, the electrode types used are Titanium, Stainless Steel, Silver and Titanium 920 where Titanium is set at anode and Stainless Steel, Silver and Titanium 920 is as cathode alternately. According to Rahman et al., (2016), the order of electrode materials arranged in terms of the production of active chlorine. The arrangement was found as follow Ti/IrO_2> Ti/RuO_2> $Ti/Pt–IrO_2$> BDD > Pt. The type of material use at anode also influence the HOCl, OCl, and Cl_2 and the generation of reactive oxygen species including OH^-, O_3 and H_2O_2 (Rahman et al., 2016; Jeong et al., 2009). Table 4.9, 4.10 and 4.11 show the physico-chemical properties for electrodes Stainless Steel, Silver and Titanium 920 respectively.

Table 4.9: Physico-chemical properties of Stainless Steel AcEW at 30 minutes.

NaCl Concentration (%)	Voltage (V)	Current (A)	pH	ORP (mV)	Free Chlorine (mg/l)	Total Chlorine (mg/l)
0.1	9	0.003	4.04	511	0.25	0.29
0.1	16	0.02	3.90	634	0.36	0.37
0.1	24	0.03	3.14	723	0.29	0.38
0.5	9	0.03	3.80	373	0.06	0.10
0.5	16	0.02	4.00	403	0.16	0.21
0.5	24	0.820	2.79	647	0.19	0.25
1.0	9	0.01	4.08	382	0.23	0.26
1.0	16	0.02	3.69	433	0.22	0.25
1.0	24	0.873	3.20	607	0.27	0.37

Table 4.10: Physico-chemical properties of Silver AcEW at 30 minutes.

NaCl Concentration (%)	Voltage (V)	Current (A)	pH	ORP (mV)	Free Chlorine (mg/l)	Total Chlorine (mg/l)
0.1	9	0.005	4.27	317	0.12	0.17
0.1	16	0.02	3.49	484	0.11	0.18
0.1	24	0.17	3.11	498	0.11	0.19
0.5	9	0.01	4.20	228	0.07	0.10
0.5	16	0.01	3.84	402	0.06	0.07
0.5	24	0.61	2.91	486	0.14	0.17
1.0	9	0.01	4.02	317	<0.05	<0.05
1.0	16	0.03	3.77	348	<0.05	<0.05
1.0	24	0.95	2.77	497	0.12	0.17

Table 4.11: Physico-chemical properties of Titanium 920 AcEW at 30 minutes.

NaCl Concentration (%)	Voltage (V)	Current (A)	pH	ORP (mV)	Free Chlorine (mg/l)	Total Chlorine (mg/l)
0.1	9	0.01	4.14	328	<0.05	<0.05
0.1	16	0.01	4.05	334	<0.05	<0.05
0.1	24	0.08	3.69	393	<0.05	<0.05
0.5	9	0.004	3.67	211	<0.05	0.06
0.5	16	0.01	2.89	329	<0.05	0.08
0.5	24	0.24	2.11	397	0.07	0.12
1.0	9	0.005	3.83	233	<0.05	0.11
1.0	16	0.01	3.00	331	0.08	0.12
1.0	24	0.40	2.28	537	0.11	0.16

From the above results, the order for the performance of electrode types is from Titanium/Titanium 920< Titanium/Silver<Titanium/Stainless Steel. The value obtained for production of free chlorine for Stainless Steel is (0.27mg/l), Silver (0.12mg/l) while Titanium 920 is (0.11mg/l). It is expected that the ability of electrode to produce higher chlorine content are depending on the value of electrical conductivity of electrode. Electrode with higher electrical conductivity will produce higher chlorine content. However, this theory cannot be used as stainless steel with

lower thermal conductivity (1.45×10^{6} S/m) can produce higher chlorine content compared to Silver and Titanium with thermal conductivity of 6.30×10^{7} S/m and 2.38×10^{6} S/m respectively. This probably happen because of the design of the lab-scale electrolyzing unit which causing low current efficiency. The current design of the lab-scale electrolyzing unit has a connector which made by stainless steel rode and hook that connected the electrode plate with DC power supply.

4.4 Shelf Life of Electrolyzed Water

For this study, the sample of 25 ml of electrolyzed water of AcEW, AlEW and NEW is collected and stored in a clean dark-brown tightly screwed close glass bottle at room temperature between 25°C to 30°C. Then, the physical and chemical properties (pH, ORP, free chlorine and total chlorine) of the samples is measured after 24 hours of storage. Electrolyzed water must be kept at optimal storage condition in order to maintain its effectiveness as sanitizer and antimicrobial agent. For AcEW, the values for ORP must be more than 800mV and pH between (2.3 - 2.7) while for AlEW, the ORP must less than -700mV and pH values between 10 and 13.

This is important because aerobic and anaerobic bacteria can optimally grow at ORP range of +200 to +800mV and -700 to +200mV respectively for AcEW and AlEW. Low pH (2.3-2.7) is needed for AcEW to sensitize or oxidize the outer layer of cell membrane of a bacterial cell to allow the Hypochlorous Acid to enter into bacterial cell (McPherson, 1993). Furthermore, the chlorine content in electrolyzed water can evaporate by exposure to atmosphere and self-decomposed over time and thus reduce the effectiveness disinfection towards food pathogens and microbial activity. The table below shows the results of physical and chemical properties of stainless steel AcEW and AlEW after 24 hours at 1.0% for 30 minutes.

Table 4.12: Physical and chemical properties of Stainless Steel AcEW at 0.1wt% NaCl concentration, 30 minutes electrolysis time and 24V for after 24 hours of storage.

pH			ORP (mV)			Free chlorine (mg/l)			Total chlorine (mg/l)		
Bef.	Aft.	Dif.	Bef.	Aft.	Dif.	Bef.	Aft.	Dif.	Bef.	Aft	Dif.
3.14	3.38	0.24	723	521	202	0.29	0.22	0.07	0.38	0.28	0.10

Table 4.12 shows that, by using stainless steel as anode, for AcEW, the ORP is decreasing over time (storage 24 hours) where it reduce from 723mV to 521mV. While the pH level is increasing from 3.14 to 3.38 where the values reverse back to neutral values of pH. For instance, the value of chlorine also reduce for free chlorine and total chlorine where 0.29 to 0.22 and 0.38 to 0.28 respectively.

Table 4.13: Physical and chemical properties of Stainless Steel AlEW at 1.0wt% NaCl concentration, 30 minutes electrolysis time and 24V for after 24 hours of storage.

pH			ORP (mV)			Free chlorine (mg/l)			Total chlorine (mg/l)		
Bef.	Aft.	Dif.	Bef.	Aft.	Dif.	Bef.	Aft.	Dif.	Bef.	Aft	Dif.
11.01	10.98	0.03	-871	-208	-663	0.19	0.17	0.02	0.27	0.23	0.04

Table 4.13 shows that the values of ORP for AlEW is increased with time. For instance at 1.0 % NaCl concentration, the ORP is increased from -871mV to -208mV. The pH values for AlEW is decreasing towards the value of neutral values of pH from 11.01 to 10.98. At The effectiveness of electrolyzed water is reduced after 24 hours of storage where physical and chemical properties average changed shows the reduction in pH, ORP, free chlorine where for AcEW 7.64%, 27.9% and 24.1% while for AlEW 0.27%, 76% and 10.5% respectively in percentage of reduction. AcEW with weaker acidity, lower ORP and lower chlorine content are not sufficient enough as

sanitiser and AlEW with weaker alkalinity and higher ORP and less chlorine content are not suitable as cleaning medium.

4.5 Response Surface Methodology for Optimization usage of Electrolyzed Water

For this study, Response Surface Methodology (RSM) and Box-Behnken design (BBD) were applied to evaluate the effects of three independent variables (NaCl concentration, voltage and electrolysis time) on the four response of physical and chemical properties (pH, ORP, free chlorine and total chlorine) for three types of electrode materials (Stainless steel, silver and Titanium 920).

Based on preliminary data, BBD had three levels (-1, 0, +1) where it indicated NaCl concentration (0.1%, 0.5% and 1.0%), voltage (9V, 16V and 24V) and electrolysis time (10 minutes, 20 minutes and 30 minutes) respectively. For this study, the desirability function was selected to optimize process variable involve to achieve the highest free and total chlorine content. For BBD, a desirability approach finds the operating conditions that provide with the most suitable or 'desirable' response values after the preference of the goal of the four response is set. The data were analysed by analysis of variance (ANOVA) using Design-Expert 11.0 program software by Stat-Ease, Inc. Minneapolis, MN, USA.

For the optimization process, each goal is set as follow where to maximize oxidation reduction potential, free and total chlorine production in electrolyzed water produced where chlorine compound and ORP or combinations of all these factors are responsible in disinfecting the microbial activity by AcEW (Kim et al., 2000; Park et al., 2004; Liu et al., 2006). The goals for each responses is summarised as in Table 4.15 for AcEW and Table 4.16 for AlEW.

4.5.1 Development and analysis of the mathematical models.

For the development of mathematical models, the BBD was investigated using design expert software. Multiple linear regression analyses of the experimental data yielded second order polynomials models for both AcEW and AlEW in predicting ORP, free chlorine and total chlorine. While for ph, analyses experimental data yielded linear model for AcEW and 2FI model for AlEW.

For AcEW:

$$pH = 4.41 - 0.0262A - 0.8150B - 0.3338C$$ **(Equation 1)**

$$ORP = 306 - 75.25A + 85.625B + 89.375C - 30.75AB - 72.25AC + 61BC + 115.25A^2 + 54.5B^2 + 36C^2$$ **(Equation 2)**

$$FC = 0.3 + 0.015A + 0.03875B + 0.04125C - 0.0775AB - 0.0075AC + 0.02BC + 0.0375A^2 - 0.125B^2 - 0.05C^2$$ **(Equation 3)**

$$TC = 0.36 + 0.025A + 0.04B + 0.035C - 0.0725AB - 0.0275AC + 0.0325BC + 0.01125A^2 - 0.13875B^2 - 0.04875C^2$$ **(Equation 4)**

For AlEW:

$$pH = 9.68 - 0.66375A + 0.785B + 1.29C + 0.3925AB + 0.68AC - 0.7975BC$$ **(Equation 5)**

$$ORP = -74.375A - 95.375B - 350.75C - 34.5AB - 168.25AC + 12.75BC + 121.25A^2 - 81.75B^2 - 228C^2$$ **(Equation 6)**

$$FC = 0.11 + 0.0287A + 0.0138B + 0.04C + 0.0125AB - 0.02AC + 0.005BC + 0.00875A^2 - 0.02625B^2 + 0.03625C^2$$ **(Equation 7)**

$$TC = 0.2 + 0.0262A + 0.0025B + 0.0688C + 0.02AB - 0.0575AC - 0.005BC + 0.0037A^2 - 0.08375B^2 + 0.02875C^2$$ **(Equation 8)**

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 4.14: ANOVA result of P-value and R^2 for AcEW and AlEW.

Responses	**AcEW**		**AlEW**	
	P value	R^2	P value	R^2
pH	0.0498	0.44	0.0021	0.94
ORP	0.0005	0.97	0.0015	0.94
Free Chlorine	0.0019	0.91	0.0031	0.95
Total Chlorine	0.0014	0.92	0.0278	0.87

The mathematical model was evaluated by ANNOVA. Based on the low probability value ($P<0.05$) indicates that it is significant. Regression coefficients (R^2), which should be >0.80 for a good model fit. For AcEW, R^2 values for pH, ORP, free chlorine and total chlorine are 0.44, 0.97, 0.91 and 0.92 respectively. Only pH obtained R^2 values <0.80, this is probably because pH is not significantly affected by the factors (NaCl concentration, electrolysis time and voltage).

Table 4.15: Criteria and limit of the numerical optimization of the responses of Stainless Steel AcEW.

Response(s)	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight
pH	In range	2.65	3.30	1	1
ORP (mV)	maximise	268	713	1	1
Free Chlorine (mg/l)	maximise	0.05	0.36	1	1
Total Chlorine (mg/l)	maximise	0.07	0.37	1	1

Table 4.16: Criteria and limit of the numerical optimization of the responses of Stainless Steel AlEW.

Response(s)	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight
pH	In range	10.00	11.80	1	1
ORP (mV)	minimise	-1000	-800	1	1
Free Chlorine (mg/l)	maximise	0.05	0.20	1	1
Total Chlorine (mg/l)	maximise	0.05	0.37	1	1

The results shows that electrode stainless steel is selected out of the three types of electrode material since the free and total chlorine production is higher compared from silver and titanium 920. From the BBD, multiple linear regression analyses of the experimental data yielded linear model for predicting pH, second order polynomial models for predicting ORP, free chlorine and total chlorine.

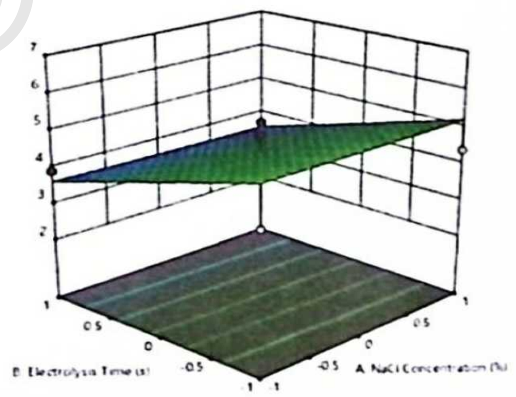
According to the numerical optimization, the desirability function generated the predicted optimum condition at maximum desirability index 0.970 (97 %) for Stainless steel AcEW and maximum desirability index 0.495 (49.5%) for Stainless steel AlEW was obtained.

Table 4.17: List of desirability of the solutions for Stainless Steel AcEW.

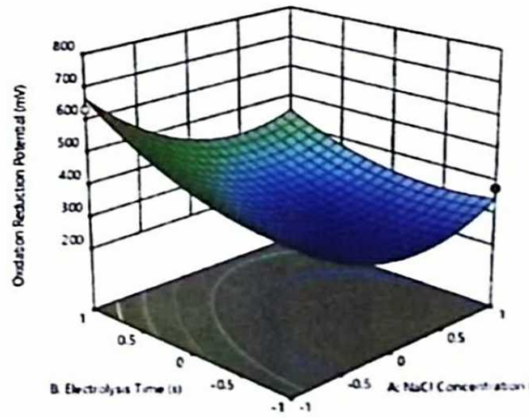
NaCl Conc.	Electrolysis Time	Volt	pH	ORP	FC	TC	Desirability	
-1.000	**0.983**	**1.000**	**3.30**	**921.163**	**0.33**	**0.37**	**0.970**	**Selected**
-1.000	0.986	0.992	3.30	919.842	0.33	0.37	0.969	
-1.000	0.988	0.989	3.30	919.006	0.33	0.37	0.969	
-0.999	0.992	0.979	3.30	917.280	0.33	0.37	0.968	

From the desirability approach obtained for Stainless Steel AcEW, the predicted optimum condition for factors variable is at 0.1wt% NaCl concentration, 30 minutes electrolysis time and 24V in order to gain the optimum values of responses 3.30 pH, 921.163 mV, 0.33 mg/l free chlorine and 0.37 mg/l total chlorine. If the desirability is approaching zero, it means that there are some compromises are necessary to satisfy the criteria.

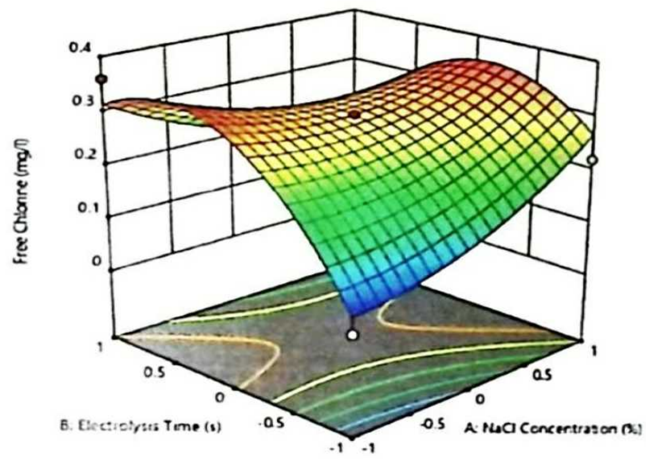
a.



b.



c.



d.

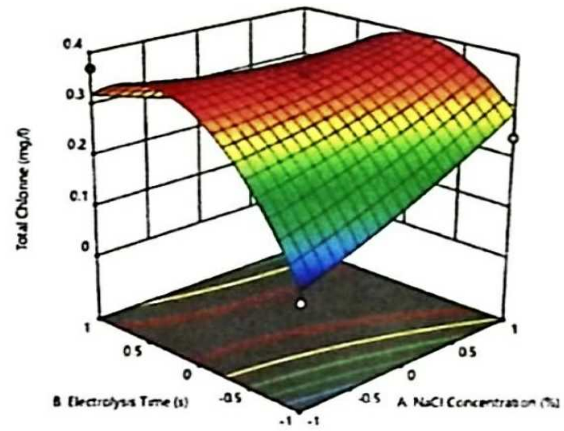


Figure 4.1: Analysis graph profile for Stainless steel AcEW of factors A: NaCl concentration and B: Electrolysis time vs. (a) pH, (b)Oxidation-reduction potential, (c) free chlorine and (d) total chlorine.

Table 4.18: List of desirability of the solutions for Stainless Steel AlEW.

NaCl Conc.	Electrolysis Time	Volt	pH	ORP	FC	TC	Desirability	
-1.000	**1.000**	**1.000**	**11.37**	**-898.996**	**0.21**	**0.20**	**0.495**	**Selected**
0.988	1.000	1.000	11.36	-898.566	0.21	0.20	0.493	
0.977	1.000	1.000	11.36	-898.129	0.21	0.20	0.491	
0.937	1.000	1.000	11.34	-896.347	0.21	0.20	0.482	

From the desirability approach obtained for Stainless Steel AlEW, the predicted optimum condition for factors variable is at 1.0wt% NaCl concentration, 30 minutes electrolysis time and 24V in order to gain the optimum values of responses 11.37 pH, -898.996mV ORP, 0.21mg/l free chlorine and 0.20mg/l total chlorine.

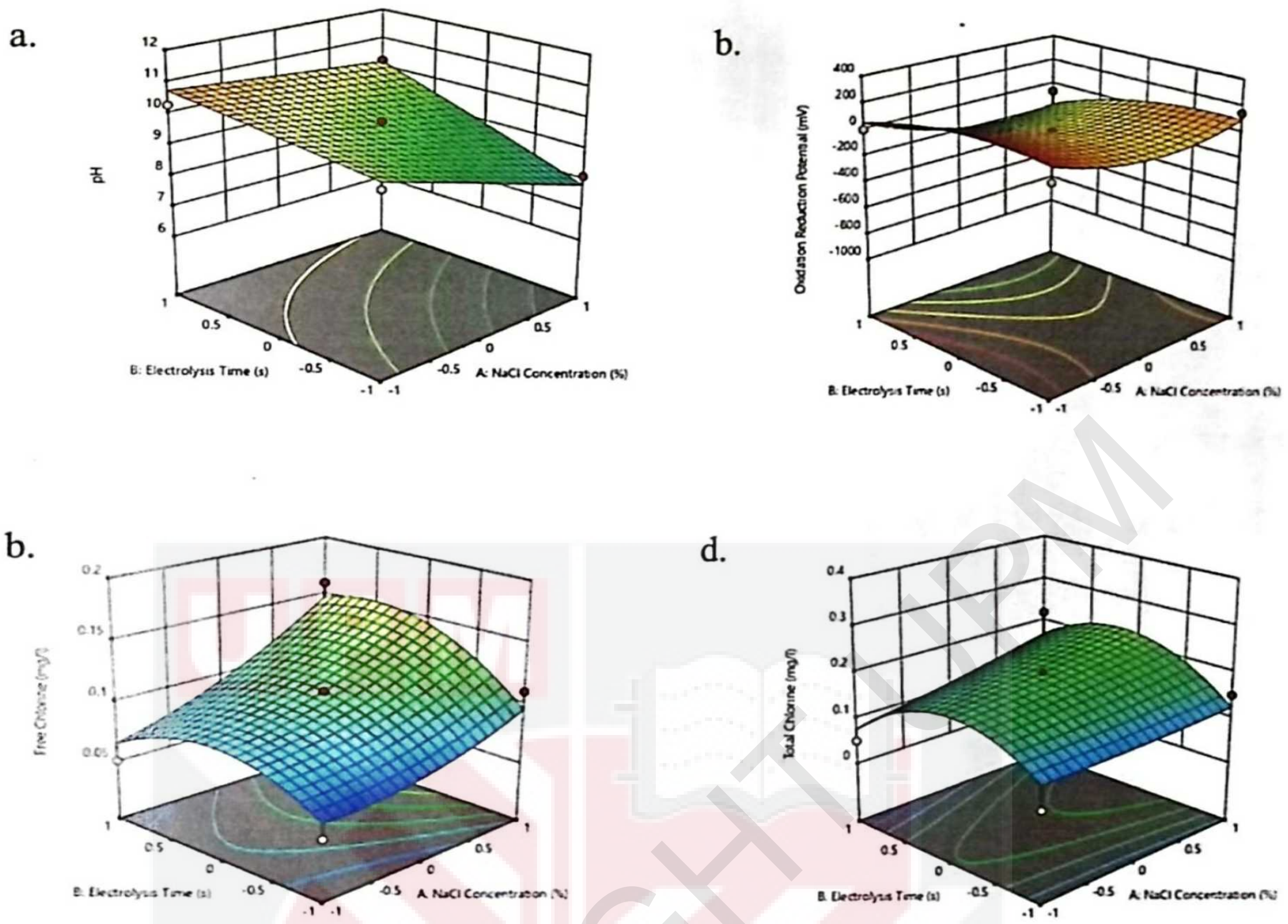


Figure 4.2: Analysis graph profile for Stainless steel AlEW of factors A: NaCl concentration and B: Electrolysis time vs. (a)pH, (b)Oxidation-reduction potential, (c) free chlorine and (d) total chlorine.

4.6 Validation of Optimization of Electrolyzed Water

Validation experiments and validation analyses are conducted to confirm the data precision by comparing the data measured and experimental data. Thus, a validation experiment need to perform under the optimized conditions. The lab scale electrolyzing unit is used to validate the result from the numerical optimization result. When determining the optimal conditions for the responses (pH, ORP, free chlorine & total chlorine), the three factors (NaCl concentration, voltage and electrolysis time) need to be taken into account.

From the numerical optimization, the optimized conditions for stainless steel AcEW consisted of a 0.1wt% NaCl concentration, 30 minutes electrolysis time and 24 V to produced 3.30 pH, 921.163mV, 0.33mg/l free chlorine and 0.37mg/l total chlorine. For stainless steel AlEW, the optimized condition consisted of a 1.0 wt% NaCl concentration, 30 minutes electrolysis time and 24 V in order to produce the optimum values of responses 11.37 pH, -898.996mV, 0.21mg/l free chlorine and 0.20mg/l total chlorine. To validate the data, two experiment were carried out under optimum condition and the experimental values for AcEW and AlEW are presented in Table 4.19 and 4.20.

Table 4.19: Predicted and actual responses for optimized process for Stainless steel AcEW.

Response (s)	Values	
	Predicted	Experimental
pH	3.30	3.27±0.05
ORP(mV)	921.163	921.114±0.5
Free Chlorine (mg/l)	0.33	0.27±0.05
Total Chlorine (mg/l)	0.37	0.30±0.05

Table 4.20: Predicted and actual responses for optimized process for Stainless steel AlEW.

Response (s)	Values	
	Predicted	Experimental
pH	11.37	11.44±0.05
ORP	-898.996	889.749±0.5
Free Chlorine	0.21	0.24±0.05
Total Chlorine	0.20	0.25±0.05

P-values less than 0.0500 indicate model terms are significant while values greater than 0.1000 indicate the model terms are not significant.

4.7 Conclusion

An investigation of the effect of electrolyzing parameters NaCl concentration (0.1, 0.5, 1.0wt %), Voltage (9, 16, 24 V), electrolysis time (10, 20, 30 minutes) is developed to study the performance of pH, ORP, free chlorine, total chlorine DO and temperature for the production of electrolyzed water. The result of physical and chemical characteristic (pH, ORP, free chlorine and total chlorine) from the lab work by using lab scale electrolyzing unit is analysed and optimized by using Response Surface Methodology (RSM). From the result, stainless steel is selected because it has the highest chlorine production compared to other electrode material. The optimized conditions for stainless steel AcEW are 0.1wt% NaCl concentration, 30 minutes electrolysis time and 24 V to produced 3.30 pH, 921.163mV, 0.33mg/l free chlorine and 0.37mg/l total chlorine. For stainless steel AlEW, the optimized condition consisted of a 1.0 wt% NaCl concentration, 30 minutes electrolysis time and 24 V in order to produce the optimum values of responses 11.37 pH, -898.996mV, 0.21mg/l free chlorine and 0.20mg/l total chlorine.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

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

5.1 Conclusion on design of experiment

In food industry, effective cleaning system is required and compulsory to ensure the safety of the food product produced. The cleaning of machines and equipment in food industry need to deal with the bacteria and microbial activity to avoid food cross-contamination and growth of microbes. The problem faced by the food industry is the application of commercial cleaning chemicals are common and costly where the cost of cleaning includes water, energy, chemical and wastewater treatment costs. Thus an electrolyzed water is produced to serve as a green cleaning system which have the same ability as the commercial cleaning chemical and at the same time reduce the impact to the environment.

For this study, the experiment for determining the relation between electrolyzing parameter and physical and chemical properties is done by using a laboratory scale electrolyzing unit. From this study, electrode Stainless steel is selected since it has the higher production of chlorine where chlorine contain Hypochlorous Acid (HOCL) which enhancing the performance of electrolyzed water by oxidizing and kill the bacterial cells (Park et al., 2004; Liu et al., 2006; Zhang et al., 2017; McPherson,1993). RSM analysis indicated good agreement between the predicted and experimental values.

From the RSM and BBD, an optimal condition for AcEW is obtained where 0.1wt% NaCl concentration, 30 minutes electrolysis time and 24 V to produced 3.30 pH, 921.163mV, 0.33mg/l free chlorine and 0.37mg/l total chlorine. For AlEW, the optimized condition consisted of a 1.0wt% NaCl concentration, 30 minutes electrolysis time and 24V in order to produce the optimum values of responses 11.37 pH values, -898.996mV, 0.21mg/l free chlorine and 0.20mg/l total chlorine.

5.2 Recommendation for future works

The trends of data obtained may not increase or decrease smoothly is might because of low current efficiency due to the usage of stainless steel rode and hook connect to the electrode plate and power supply. The condition may have slight effect on the result obtained and to overcome and increase the improvements on this problem is by changing the stainless steel rode and hook to copper material to increase the current efficiency. Moreover, the increment of current efficiency can be made by ensuring even distribution of current to all electrodes, electrical contacts are clean and electrodes are equally spaced and hanging. Further modification and recommendation of this EW system can be performed to achieve optimal conditions.

REFERENCES

Abadias, M., Usall, J., Oliveira, M., Alegre, I., & Viñas, I. (2008). Efficacy of neutral electrolyzed water (NEW) for reducing microbial contamination on minimally-processed vegetables, *123*, 151–158. https://doi.org/10.1016/j.ijfoodmicro.2007.12.008

Access, O. (2013). Development of device producing electrolyzed water for home care Development of device producing electrolyzed water for home. https://doi.org/10.1088/1742-6596/450/1/012035

Aq, M. I. A. L., Ugiyama, J. S., & Sobe, S. I. (n.d.). Review Applications of Electrolyzed Water in Agriculture & Food Industries, *1*.

Bezerra, M. A., Santelli, R. E., Oliveira, E. P., Villar, L. S., & Escaleira, L. A. (2008). Response surface methodology (RSM) as a tool for optimization in analytical chemistry. *Talanta*, *76*(5), 965–977. https://doi.org/10.1016/j.talanta.2008.05.019

Cao, W., Zhu, Z. W., Shi, Z. X., Wang, C. Y., & Li, B. M. (2009). International Journal of Food Microbiology Ef fi ciency of slightly acidic electrolyzed water for inactivation of Salmonella enteritidis and its contaminated shell eggs. *International Journal of Food Microbiology*, *130*(2), 88–93. https://doi.org/10.1016/j.ijfoodmicro.2008.12.021

Commission, E. (2005). Cleaning Technology and Hygiene in Food Industry, 1–22.

Cui, X., Shang, Y., Shi, Z., Xin, H., & Cao, W. (2009). Physicochemical properties and bactericidal efficiency of neutral and acidic electrolyzed water under different storage conditions. *Journal of Food Engineering*, *91*(4), 582–586. https://doi.org/10.1016/j.jfoodeng.2008.10.006

Ding, T., Rahman, S. M. E., & Oh, D. (2011). Inhibitory effects of low concentration electrolyzed water and other sanitizers against foodborne pathogens on oyster mushroom. *Food Control*, *22*(2), 318–322. https://doi.org/10.1016/j.foodcont.2010.07.030

Forghani, F., Park, J. H., & Oh, D. H. (2015). Effect of water hardness on the production and microbicidal efficacy of slightly acidic electrolyzed water. *Food Microbiology*, *48*, 28–34. https://doi.org/10.1016/j.fm.2014.11.020

Fresh-cut, A., Typhimurium, S., & O, E. (2003). The Effect of pH on Inactivation of Pathogenic Bacteria on Fresh-cut Lettuce by Dipping Treatment with Electrolyzed Water, *68*(3), 1013–1017.

Guentzel, J. L., Liang, K., Callan, M. A., Emmons, S. A., & Dunham, V. L. (2008). ARTICLE IN PRESS FOOD Reduction of bacteria on spinach, lettuce, and surfaces in food service areas using neutral electrolyzed oxidizing water, *25*, 36–41. https://doi.org/10.1016/j.fm.2007.08.003

Guide, M. I. (n.d.). Chapter 5 Cleaning, (September 2017).

Han, D., Hung, Y. C., & Wang, L. (2018). Evaluation of the antimicrobial efficacy of neutral electrolyzed water on pork products and the formation of viable but nonculturable (VBNC) pathogens. *Food Microbiology*, *73*, 227–236. https://doi.org/10.1016/j.fm.2018.01.023

Hricova, D., Stephan, R., & Zweifel, C. (2008). Electrolyzed Water and Its Application in the Food Industry, *71*(9), 1934–1947.

Hsu, G. W., Hsia, C., & Hsu, S. (2015). ScienceDirect Effects of electrode settings on chlorine generation efficiency of electrolyzing seawater, *3*, 5–10. https://doi.org/10.1016/j.jfda.2015.06.007

Hsu, G. W., Lu, Y., & Hsu, S. (2016). ScienceDirect Effects of electrolysis time and electric potential on chlorine generation of electrolyzed Deep Ocean water, *5*(1), 5–11. https://doi.org/10.1016/j.jfda.2016.07.001

Hsu, S., & Kao, H. (2004). Effects of storage conditions on chemical and physical properties of electrolyzed oxidizing water, *65*, 465–471. https://doi.org/10.1016/j.jfoodeng.2004.02.009

Huang, Y., Hung, Y., Hsu, S., & Huang, Y. (2008). Application of electrolyzed water in the food industry, *19*, 329–345. https://doi.org/10.1016/j.foodcont.2007.08.012

Issa-zacharia, A., Kamitani, Y., Miwa, N., Muhimbula, H., & Iwasaki, K. (2011). Application of slightly acidic electrolyzed water as a potential non-thermal food sanitizer for decontamination of fresh ready-to-eat vegetables and sprouts. *Food Control*, *22*(3–4), 601–607. https://doi.org/10.1016/j.foodcont.2010.10.011

Issa-zacharia, A., Kamitani, Y., Morita, K., & Iwasaki, K. (2010). Sanitization potency of slightly acidic electrolyzed water against pure cultures of Escherichia coli and

Staphylococcus aureus , in comparison with that of other food sanitizers. *Food Control*, *21*(5), 740–745. https://doi.org/10.1016/j.foodcont.2009.11.002

Issa-zacharia, A., Kamitani, Y., Tiisekwa, A., Morita, K., & Iwasaki, K. (2010). In vitro inactivation of Escherichia coli , Staphylococcus aureus and Salmonella spp . using slightly acidic electrolyzed water. *JBIOSC*, *110*(3), 308–313. https://doi.org/10.1016/j.jbiosc.2010.03.012

Itatio, A. N. (n.d.). Lean i n g &.

Izumi, H. (1999). Electrolyzed Water as a Disinfectant for Fresh-cut Vegetables, *64*(2), 536–539.

Jeong, J., Kim, C., & Yoon, J. (2009). The effect of electrode material on the generation of oxidants and microbial inactivation in the electrochemical disinfection processes. *Water Research*, *43*(4), 895–901. https://doi.org/10.1016/j.watres.2008.11.033

Keskinen, L. A., Burke, A., & Annous, B. A. (2009). International Journal of Food Microbiology Ef fi cacy of chlorine , acidic electrolyzed water and aqueous chlorine dioxide solutions to decontaminate Escherichia coli O157 : H7 from lettuce leaves ☆. *International Journal of Food Microbiology*, *132*(2–3), 134–140. https://doi.org/10.1016/j.ijfoodmicro.2009.04.006

Kim, C., Hung, Y. C., & Brackett, R. E. (2000). Roles of oxidation-reduction potential in electrolyzed oxidizing and chemically modified water for the inactivation of food-related pathogens. *Journal of Food Protection*, *63*(1), 19–24.

Kim, C., Hung, Y., & Brackett, R. E. (2000). Efficacy of electrolyzed oxidizing (EO) and chemically modified water on different types of foodborne pathogens, *61*, 199–207.

Koide, S., Takeda, J., Shi, J., Shono, H., & Atungulu, G. G. (2009). Disinfection efficacy of slightly acidic electrolyzed water on fresh cut cabbage. *Food Control*, *20*(3), 294–297. https://doi.org/10.1016/j.foodcont.2008.05.019

Koseki, S., Yoshida, K., Isobe, S., & Itoh, K. (2001). Decontamination of Lettuce Using Acidic Electrolyzed Water, *64*(5), 652–658.

Koseki, S., Yoshida, K., & Kamitani, Y. (2004). ARTICLE IN PRESS Effect of mild heat pre-treatment with alkaline electrolyzed water on the efficacy of acidic electrolyzed water against Escherichia coli O157 : H7 and Salmonella on Lettuce, *21*, 559–566. https://doi.org/10.1016/j.fm.2003.11.004

Liao, L. B., Chen, W. M., & Xiao, X. M. (2007). The generation and inactivation mechanism of oxidation – reduction potential of electrolyzed oxidizing water, *78*, 1326–1332. https://doi.org/10.1016/j.jfoodeng.2006.01.004

Liu, C., & Su, Y. C. (2006). Efficiency of electrolyzed oxidizing water on reducing Listeria monocytogenes contamination on seafood processing gloves. *International Journal of Food Microbiology*, *110*(2), 149–154. https://doi.org/10.1016/j.ijfoodmicro.2006.02.004

Liyana-Pathirana, C., & Shahidi, F. (2005). Optimization of extraction of phenolic compounds from wheat using response surface methodology. *Food Chemistry*, *93*(1), 47–56. https://doi.org/10.1016/j.foodchem.2004.08.050

Minich, D. M., & Bland, J. S. (n.d.). *No Title* (Vol. 2).

Oomori, T., Oka, T., Inuta, T., & Arata, Y. (2000). The efficiency of disinfection of acidic electrolyzed water in the presence of organic materials. *Analytical Sciences*, *16*(4), 365–369. https://doi.org/10.2116/analsci.16.365

Ozer, N. P., & Demirci, A. (2006). Electrolyzed oxidizing water treatment for decontamination of raw salmon inoculated with Escherichia coli O157 : H7 and Listeria monocytogenes Scott A and response surface modeling, *72*, 234–241. https://doi.org/10.1016/j.jfoodeng.2004.11.038

Pangloli, P., & Hung, Y. (2009). Efficacy of electrolyzed water produced from different principles, 1–4.

Park, H., Hung, Y. C., & Kim, C. (2002). Effectiveness of electrolyzed water as a sanitizer for treating different surfaces. *Journal of Food Protection*, *65*(8), 1276–1280. https://doi.org/10.1016/j.jvs.2005.05.014

Park, H., Hung, Y., & Brackett, R. E. (2002). Antimicrobial effect of electrolyzed water for inactivating Campylobacter jejuni during poultry washing, *72*, 77–83.

Phuvasate, S., & Su, Y. C. (2010). Effects of electrolyzed oxidizing water and ice treatments on reducing histamine-producing bacteria on fish skin and food contact surface. *Food Control*, *21*(3), 286–291. https://doi.org/10.1016/j.foodcont.2009.06.007

Rahman, S. M. E., Ding, T., & Oh, D. (2010). International Journal of Food Microbiology Effectiveness of low concentration electrolyzed water to inactivate foodborne pathogens under different environmental conditions. *International*

Journal of Food Microbiology, *139*(3), 147–153. https://doi.org/10.1016/j.ijfoodmicro.2010.03.020

Rahman, S. M. E., Hyun, J., Wang, J., & Oh, D. (2012). Stability of low concentration electrolyzed water and its sanitization potential against foodborne pathogens. *Journal of Food Engineering*, *113*(4), 548–553. https://doi.org/10.1016/j.jfoodeng.2012.07.011

Rahman, S. M. E., Khan, I., & Oh, D. (2016). Electrolyzed Water as a Novel Sanitizer in the Food Industry : Current Trends and Future Perspectives, *15*, 471–490. https://doi.org/10.1111/1541-4337.12200

Rossmeisl, J., Logadottir, A., & Nørskov, J. K. (2005). Electrolysis of water on (oxidized) metal surfaces. *Chemical Physics*, *319*(1–3), 178–184. https://doi.org/10.1016/j.chemphys.2005.05.038

Schmidt, R. H. (2015). Basic Elements of Equipment Cleaning and Sanitizing in Food Processing and Handling Operations 1, 1–11.

Summary, Q. (n.d.). WHITEPAPER Cleaning and Disinfection in Food Processing Operations.

Venkitanarayanan, K. S., Ezeike, G. O., & Doyle, M. P. (1999). Efficacy of Electrolyzed Oxidizing Water for Inactivating Escherichia coli O157 : H7 , Salmonella enteritidis , and Listeria monocytogenes Efficacy of Electrolyzed Oxidizing Water for Inactivating Escherichia coli O157 : H7 , Salmonella enteritidis ,. *Society*, *65*(9), 9–13.

Xie, J., Sun, X. H., Pan, Y. J., & Zhao, Y. (2012). Physicochemical properties and bactericidal activities of acidic electrolyzed water used or stored at different temperatures on shrimp. *FRIN*, *47*(2), 331–336. https://doi.org/10.1016/j.foodres.2011.07.041

Zadorozhny, J. G., Naida, I. N., Gory, S., Dzheiranishvili, N. V, Niebling, P. E., & Butin, S. K. (1995). F / am Hm.

Zainuddin, M. F., Shamsudin, R., Mokhtar, M. N., & Ismail, D. (2014). com Physicochemical Properties of Pineapple Plant Waste Fibers from the Leaves and Stems of Different Varieties, *9*(3), 5311–5324.

Zeng, K., & Zhang, D. (2010). Recent progress in alkaline water electrolysis for hydrogen production and applications. *Progress in Energy and Combustion Science*, *36*(3), 307–326. https://doi.org/10.1016/j.pecs.2009.11.002

Zeng, X., Tang, W., Ye, G., Ouyang, T., Tian, L., Ni, Y., & Li, P. (n.d.). Studies on Disinfection Mechanism of Electrolyzed Oxidizing Water on E . coli and Staphylococcus aureus. https://doi.org/10.1111/j.1750-3841.2010.01649.x

Cost-efficient crate cleaning in the food industry and logistics. (n.d.).

Microbial attachment to food and food contact surfaces. (2016), *4526*(FEBRUARY 2001). https://doi.org/10.1016/S1043-4526(01)43008-7

University of Georgia College of Agricultural and Environmental Sciences Cooperative Extension Service. (n.d.).

Principle and characteristics of electrolyzed acid water Principle of electrolyzed acid water. (n.d.), 1–6.

APPENDICES

TABLE OF RESULT

Table 1: Titanium/Stainless steel (Acidic Electrolysed water) Anode

NaCl concentration (%)	Voltage (V)	Amperage (A)	pH			ORP			Free chlorine			Total chlorine			Dissolved Oxygen			Temperature		
			Before	After	Diff.	Before	After	Diff.	Before	After	Diff.	Before	After	Diff.	Before	After	Diff.	Before	After	Diff.
10 minutes																				
0.1	9	0.003	6.18	5.27	0.91	297	265	32	<0.05	<0.05		<0.05	0.06		15.3	15.9	0.6	25.5	25.4	0.1
0.1	16	0.05	6.16	4.14	2.02	300	457	157	<0.05	0.05		<0.05	0.07		19.2	19.5	0.3	23.1	23.2	0.1
0.1	24	0.05	6.04	3.87	2.17	240	648	408	<0.05	0.07		<0.05	0.10		19.4	21.2	1.8	23.8	23.4	0.4
0.5	9	0.004	6.05	5.47	0.58	331	268	63	<0.05	0.10		<0.05	0.16		20.1	19.9	0.2	24.0	26.7	2.7
0.5	16	0.013	5.98	4.66	1.32	239	372	133	<0.05	0.23		<0.05	0.26		17.5	17.8	0.3	26.6	26.8	0.2
0.5	24	0.010	6.00	6.72	0.72	250	298	48	<0.05	0.15		<0.05	0.18		17.2	18.4	1.2	26.7	26.7	0.0
1.0	9	0.005	5.98	5.93	0.05	333	363	30	<0.05	0.19		<0.05	0.23		17.7	19.3	1.6	25.0	24.8	0.2
1.0	16	0.020	6.02	4.37	1.65	321	379	58	<0.05	0.22		<0.05	0.24		17.6	18.1	0.5	25.1	25.0	0.1
1.0	24	0.310	6.11	4.02	2.09	303	389	86	<0.05	0.23		<0.05	0.25		18.0	18.1	0.1	24.8	25.0	0.2
20 minutes																				
0.1	9	0.003	6.46	4.61	1.85	301	363	62	<0.05	0.22		<0.05	0.23		15.4	16.9	1.5	25.2	25.4	0.2
0.1	16	0.03	6.14	3.75	2.39	282	569	287	<0.05	0.24		<0.05	0.28		19.5	20.0	0.5	23.8	23.1	0.7
0.1	24	0.04	6.12	3.49	2.63	285	713	428	<0.05	0.31		<0.05	0.34		20.1	20.7	0.6	24.0	23.4	0.6
0.5	9	0.005	5.89	4.64	1.25	354	371	17	<0.05	0.18		<0.05	0.31		20.1	20.8	0.7	24.4	24.0	0.4
0.5	16	0.03	6.00	4.82	1.18	250	306	56	<0.05	0.30		<0.05	0.36		16.4	16.1	0.3	28.1	28.0	0.1
0.5	24	0.47	6.01	3.12	2.89	253	474	221	<0.05	0.25		<0.05	0.31		17.0	18.7	1.7	26.8	26.1	0.7
1.0	9	0.005	5.99	4.83	1.16	352	346	6	<0.05	0.28		<0.05	0.36		17.5	18.9	1.4	25.2	24.9	0.3

1.0	16	0.014	5.86	4.51	1.35	334	383	49	<0.05	0.30		<0.05	0.33		16.3	17.2	0.9	25.7	25.6	0.1
1.0	24	0.502	6.02	3.04	2.98	312	407	95	<0.05	0.34		<0.05	0.36		18.1	18.0	0.1	25.1	25.0	0.1
30 minutes																				
0.1	9	0.003	6.07	4.04	2.03	317	511	194	<0.05	0.25		<0.05	0.29		19.7	20.0	0.3	24.3	24.1	0.2
0.1	16	0.02	6.16	3.90	2.26	270	634	364	<0.05	0.36		<0.05	0.37		20.7	20.9	0.2	23.0	23.2	0.2
0.1	24	0.03	6.15	3.14	3.01	314	723	409	<0.05	0.29		<0.05	0.38		20.5	20.6	0.1	25.0	24.5	0.5
0.5	9	0.03	5.75	3.80	1.95	281	373	92	<0.05	0.06		<0.05	0.10		19.2	20.5	1.3	27.8	25.8	2.0
0.5	16	0.02	5.64	4.00	1.64	312	403	91	<0.05	0.16		<0.05	0.21		15.7	16.2	0.5	27.3	27.4	0.1
0.5	24	0.820	5.95	2.79	3.16	252	647	395	<0.05	0.19		<0.05	0.25		17.1	17.7	0.6	27.1	26.0	1.1
1.0	9	0.01	5.90	4.08	1.82	363	382	19	<0.05	0.23		<0.05	0.26		17.9	18.1	0.2	25.2	25.0	0.2
1.0	16	0.02	5.65	3.69	1.96	347	433	86	<0.05	0.22		<0.05	0.25		16.7	16.5	0.2	25.8	25.4	0.4
1.0	24	0.873	5.71	3.20	2.51	328	607	279	<0.05	0.27		<0.05	0.37		17.0	17.1	0.1	24.7	24.8	0.1

Table 2: Titanium/Stainless steel (Alkaline Electrolysed water) Cathode

NaCl concentration (%)	Voltage (V)	Amperage (A)	pH			ORP			Free chlorine			Total chlorine			DO			Temperature		
			Before	After	Diff.	Before	After	Diff.	Before	After	Diff.	Before	After	Diff.	Before	After	Diff.	Before	After	Diff.
10 minutes																				
0.1	9	0.003	6.18	6.67	0.49	297	241	56	<0.05	0.05		<0.05	0.07		15.3	15.1	0.2	25.5	25.5	0.0
0.1	16	0.05	6.16	9.74	3.58	300	69	231	<0.05	0.05		<0.05	0.06		19.2	20.3	1.1	23.1	23.1	0.0
0.1	24	0.05	6.04	9.80	3.76	240	29	211	<0.05	0.05		<0.05	0.10		19.4	21.1	1.7	23.8	23.3	0.5
0.5	9	0.004	6.05	6.65	0.60	331	244	87	<0.05	0.07		<0.05	0.08		20.1	19.9	0.2	24.0	26.7	2.7
0.5	16	0.013	5.98	8.50	2.52	239	102	137	<0.05	0.08		<0.05	0.10		17.5	16.7	0.8	26.6	26.8	0.2
0.5	24	0.010	6.00	9.40	3.40	250	54	4	<0.05	0.09		<0.05	0.12		17.2	18.2	1.0	26.7	26.8	0.1
1.0	9	0.005	5.98	6.33	0.35	333	305	28	<0.05	0.10		<0.05	0.14		17.7	18.5	0.8	25.0	24.8	0.2
1.0	16	0.02	6.02	8.12	2.10	321	145	176	<0.05	0.11		<0.05	0.15		17.6	18.3	0.7	25.1	25.1	0.0
1.0	24	0.310	6.11	9.47	3.36	303	85	218	<0.05	0.10		<0.05	0.14		18.0	18.1	0.1	24.8	25.0	0.2
20 minutes																				
0.1	9	0.003	6.46	9.91	3.45	301	161	140	<0.05	0.08		<0.05	0.12		15.4	15.2	0.2	25.2	25.3	0.1
0.1	16	0.03	6.14	10.02	3.88	282	22	260	<0.05	0.07		<0.05	0.16		19.5	20.5	1.0	23.8	23.4	0.4
0.1	24	0.04	6.12	10.69	4.57	285	-70	355	<0.05	0.20		<0.05	0.37		20.1	20.6	0.5	24.0	23.4	0.6
0.5	9	0.005	5.89	7.53	1.64	354	150	204	<0.05	0.08		<0.05	0.19		20.1	20.9	0.8	23.8	24.0	0.2
0.5	16	0.003	6.00	9.85	3.85	250	0	250	<0.05	0.11		<0.05	0.20		16.4	16.1	0.3	28.1	27.9	0.2
0.5	24	0.470	6.01	11.25	5.24	253	-617	870	<0.05	0.14		<0.05	0.23		17.0	16.7	0.3	26.8	25.2	1.6
1.0	9	0.005	5.99	6.73	0.74	352	193	159	<0.05	0.15		<0.05	0.21		17.5	19.6	2.1	25.2	24.8	0.4
1.0	16	0.014	5.86	9.44	3.58	334	30	304	<0.05	0.18		<0.05	0.20		16.3	16.4	0.1	25.7	25.3	0.4
1.0	24	0.502	6.02	10.23	4.21	312	-711	1023	<0.05	0.19		<0.05	0.23		18.1	18.3	0.2	25.1	25.0	0.1
30 minutes																				

0.1	9	0.003	6.07	9.87	3.8	317	47	270	<0.05	0.05		<0.05	0.05		19.7	20.0	0.3	24.3	24.1	0.2
0.1	16	0.03	6.16	10.28	4.12	270	3	267	<0.05	0.05		<0.05	0.05		20.7	21.1	0.4	23.0	23.1	0.1
0.1	24	0.03	6.15	10.94	4.79	314	-192	506	<0.05	0.06		<0.05	0.08		20.5	20.7	0.2	25.0	24.6	0.4
0.5	9	0.03	5.75	10.06	4.31	281	-28	309	<0.05	0.09		<0.05	0.07		19.2	19.9	0.7	27.8	26.2	1.6
0.5	16	0.02	5.64	10.39	4.75	312	-38	350	<0.05	0.11		<0.05	0.14		15.7	16.0	0.3	27.3	27.3	0.0
0.5	24	0.820	5.95	11.47	5.52	252	-838	109 0	<0.05	0.18		<0.05	0.20		17.1	16.4	0.7	27.1	26.5	0.6
1.0	9	0.01	5.90	9.72	3.82	363	16	347	<0.05	0.20		<0.05	0.21		17.9	18.8	0.9	25.2	25.1	0.1
1.0	16	0.02	5.65	10.23	4.58	347	-59	406	<0.05	0.16		<0.05	0.22		16.7	15.5	1.2	25.8	25.6	0.2
1.0	24	0.873	5.71	11.01	5.30	328	-871	119 9	<0.05	0.19		<0.05	0.27		17.0	18.2	1.2	24.7	24.6	0.1

Table 3: Titanium/Silver (Acidic Electrolysed water) ANODE

NaCl concentration (%)	Voltage (V)	Amperage (A)	pH			ORP			Free chlorine			Total chlorine			DO			Temperature		
			Before	After	Diff.	Before	After	Diff.	Before	After	Diff.	Before	After	Diff.	Before	After	Diff.	Before	After	Diff.
10 minutes																				
0.1	9	0.001	5.99	4.38	1.61	300	363	63	<0.05	0.07		<0.05	0.08		3.6	4.1	0.5	22.3	22.6	0.3
0.1	16	0.02	5.82	4.22	1.6	253	416	163	<0.05	0.10		<0.05	0.15		5.7	5.4	0.3	29.2	27.9	1.3
0.1	24	0.05	6.01	3.86	2.15	299	335	36	<0.05	0.14		<0.05	0.07		4.3	4.9	0.6	23.9	23.2	0.7
0.5	9	0.01	5.99	6.36	0.37	222	221	1	<0.05	<0.05		<0.05	0.05		5.8	5.4	0.4	23.7	23.3	0.4
0.5	16	0.02	5.98	4.14	1.84	228	285	57	<0.05	<0.05		<0.05	0.05		5.7	5.2	0.5	23.8	23.3	0.5
0.5	24	0.21	6.32	3.74	2.58	248	391	143	<0.05	0.06		<0.05	0.10		6.2	6.5	0.3	23.4	23.5	0.1
1.0	9	0.01	5.61	4.30	1.31	139	159	20	<0.05	<0.05		<0.05	<0.05		6.7	6.3	0.4	23.4	23.2	0.2
1.0	16	0.02	5.39	4.28	1.11	118	319	201	<0.05	<0.05		<0.05	0.11		4.8	4.6	0.2	29.5	28.9	0.6
1.0	24	0.46	4.82	3.12	1.7	146	421	275	<0.05	0.07		<0.05	0.09		5.6	4.8	0.8	22.9	23.0	0.1
20 minutes																				
0.1	9	0.002	5.89	4.32	1.57	307	282	25	<0.05	0.10		<0.05	0.11		11.1	11.3	0.2	22.6	21.9	0.7
0.1	16	0.01	5.72	4.09	1.63	300	415	115	<0.05	<0.05		<0.05	0.07		4.5	5.7	1.2	24.2	24.1	0.1
0.1	24	0.08	5.89	3.57	2.32	264	605	341	<0.05	0.20		<0.05	0.24		5.3	4.2	1.1	25.9	24.9	1
0.5	9	0.01	6.12	4.48	1.64	226	212	14	<0.05	<0.05		<0.05	0.05		4.5	5.4	0.9	24.9	23.7	1.2
0.5	16	0.02	6.50	4.35	2.15	156	303	147	<0.05	<0.05		<0.05	<0.05		4.7	5.6	0.9	22.8	22.7	0.1
0.5	24	0.37	5.64	3.36	2.28	149	500	351	<0.05	0.07		<0.05	0.10		5.4	5.7	0.3	22.8	22.7	0.1
1.0	9	0.09	5.19	4.26	0.93	192	374	182	<0.05	<0.05		<0.05	0.07		5.5	4.8	0.7	24.0	24.6	0.6
1.0	16	0.019	5.13	3.34	1.79	216	399	183	<0.05	<0.05		<0.05	0.06		6.2	5.8	0.4	24.1	23.6	0.5
1.0	24	0.93	6.01	2.93	3.08	146	318	172	<0.05	0.08		<0.05	0.10		5.3	4.5	0.8	23.9	23.5	0.4

30 minutes																				
0.1	9	0.005	5.93	4.27	1.66	293	317	24	<0.05	0.12		<0.05	0.17		10.3	10.6	0.3	25.3	24.0	1.3
0.1	16	0.02	5.85	3.49	2.36	251	484	233	<0.05	0.11		<0.05	0.18		6.1	8.3	2.2	24.0	23.1	0.9
0.1	24	0.17	6.18	3.11	3.07	242	498	456	<0.05	0.11		<0.05	0.19		5.5	5.2	0.3	27.1	26.2	0.9
0.5	9	0.01	5.95	4.20	1.75	215	228	13	<0.05	0.07		<0.05	0.10		4.5	4.3	0.2	26.1	24.9	1.2
0.5	16	0.01	5.96	3.84	2.12	195	402	207	<0.05	0.06		<0.05	0.07		4.8	4.8	0	24.6	23.2	1.4
0.5	24	0.61	5.96	2.91	3.05	189	486	297	<0.05	0.14		<0.05	0.17		5.0	5.8	0.8	23.1	22.5	0.6
1.0	9	0.01	5.34	4.02	1.32	214	317	15	<0.05	<0.05		<0.05	<0.05		5.0	5.0	0	25.8	25.1	0.7
1.0	16	0.03	5.42	3.77	1.65	195	348	53	<0.05	<0.05		<0.05	<0.05		5.8	5.9	0.1	24.7	23.4	1.3
1.0	24	0.95	5.94	2.77	3.17	204	497	171	<0.05	0.12		<0.05	0.17		4.1	4.6	0.5	24.5	23.9	0.6

Table 4: Titanium/Silver (Alkaline Electrolysed water)

NaCl concentration (%)	Voltage (V)	Amperage (A)	pH			ORP			Free chlorine			Total chlorine			DO			Temperature		
			Before	After	Diff.	Before	After	Diff.	Before	After	Diff.	Before	After	Diff.	Before	After	Diff.	Before	After	Diff.
10 minutes																				
0.1	9	0.001	5.99	9.08	3.09	300	37	263	<0.05	<0.05		<0.05	0.06		3.6	4.6	1.0	22.3	22.4	0.1
0.1	16	0.02	5.82	9.29	3.47	253	-1	254	<0.05	0.06		<0.05	0.09		5.7	5.8	0.1	29.2	29.0	0.2
0.1	24	0.05	6.01	10.01	4	299	-153	452	<0.05	<0.05		<0.05	0.08		4.3	4.6	0.3	23.9	23.4	0.5
0.5	9	0.01	5.99	5.59	0.4	222	216	6	<0.05	<0.05		<0.05	0.05		5.8	5.5	0.3	23.7	22.7	1.0
0.5	16	0.02	5.98	10.00	4.02	228	-50	278	<0.05	<0.05		<0.05	<0.05		5.7	5.0	0.7	23.8	22.7	1.1
0.5	24	0.21	6.32	11.06	4.74	248	-185	433	<0.05	<0.05		<0.05	<0.05		6.2	6.2	0.0	23.4	23.5	0.1
1.0	9	0.01	5.61	6.02	0.41	139	162	23	<0.05	<0.05		<0.05	<0.05		6.7	5.7	1.0	23.5	23.2	0.3
1.0	16	0.02	5.39	7.34	1.95	118	4	114	<0.05	<0.05		<0.05	<0.05		4.8	4.5	0.3	29.5	28.9	0.6
1.0	24	0.46	4.82	11.09	6.27	146	-197	343	<0.05	<0.05		<0.05	0.06		5.6	4.8	0.8	22.9	23.0	0.1
20 minutes																				
0.1	9	0.002	5.89	9.15	3.26	307	88	219	<0.05	0.08		<0.05	0.10		11.1	11.7	0.6	22.6	22.0	0.6
0.1	16	0.01	5.72	9.46	3.74	300	-7	307	<0.05	<0.05		<0.05	0.06		4.5	4.3	0.2	24.2	24.0	0.2
0.1	24	0.08	5.89	10.18	4.29	264	-159	423	<0.05	0.05		<0.05	0.06		5.3	5.5	0.2	25.9	25.4	0.5
0.5	9	0.01	6.12	8.83	2.71	226	97	129	<0.05	<0.05		<0.05	<0.05		4.5	4.4	0.1	24.9	23.9	1
0.5	16	0.02	6.50	9.30	2.8	156	-27	183	<0.05	<0.05		<0.05	<0.05		4.7	5.8	1.1	22.8	22.7	0.1
0.5	24	0.37	5.64	11.15	5.51	149	-379	528	<0.05	<0.05		<0.05	<0.05		5.4	5.4	0	22.8	22.7	0.1
1.0	9	0.09	5.19	8.53	3.34	192	67	125	<0.05	<0.05		<0.05	<0.05		5.5	4.7	0.8	24.0	24.6	0.6
1.0	16	0.019	5.13	10.24	5.11	216	-135	351	<0.05	<0.05		<0.05	<0.05		6.2	5.2	1	24.1	23.6	0.5
1.0	24	0.93	6.01	11.92	5.91	146	-311	457	<0.05	<0.05		<0.05	0.08		5.3	2.9	2.4	23.9	23.3	0.6

30 minutes																				
0.1	9	0.005	5.93	8.99	3.06	293	206	87	<0.05	0.11		<0.05	0.14		10.3	10.5	0.2	25.3	24.1	1.2
0.1	16	0.02	5.85	10.57	4.72	251	-122	373	<0.05	0.05		<0.05	0.05		6.1	8.4	2.3	24.0	23.1	0.9
0.1	24	0.17	6.18	11.02	4.84	242	-326	568	<0.05	<0.05		<0.05	0.05		5.5	4.6	0.9	27.1	25.7	1.4
0.5	9	0.01	5.95	9.73	3.78	215	-1	216	<0.05	<0.05		<0.05	0.05		4.5	4.2	0.3	26.1	25.3	0.8
0.5	16	0.01	5.96	10.17	4.21	195	-55	250	<0.05	<0.05		<0.05	<0.05		4.8	4.4	0.4	24.6	23.8	0.8
0.5	24	0.61	5.96	11.51	5.55	189	-353	542	<0.05	<0.05		<0.05	<0.05		5.0	4.2	0.8	23.1	22.7	0.4
1.0	9	0.01	5.34	9.75	4.41	214	-8	222	<0.05	<0.05		<0.05	<0.05		5.0	4.5	0.5	25.8	25.1	0.7
1.0	16	0.03	5.42	10.22	4.8	195	-86	281	<0.05	<0.05		<0.05	<0.05		5.8	5.1	0.7	24.7	23.8	0.9
1.0	24	0.95	5.94	11.76	5.82	204	-365	569	<0.05	0.08		<0.05	0.10		4.1	2.5	1.6	24.5	23.9	0.6

Table 5: Titanium/Titanium 920 (Acidic Electrolysed water) ANODE

NaCl concentration (%)	Voltage (V)	Amperage (A)	pH			ORP			Free chlorine			Total chlorine			DO			Temperature		
			Before	After	Diff.	Before	After	Diff.	Before	After	Diff	Before	After	Diff	Before	After	Diff.	Before	After	Diff.
10 minutes																				
0.1	9	0.005	4.87	4.23	0.64	210	212	2	<0.05	<0.05		<0.05	<0.05		5.2	4.8	0.4	23.2	23.3	0.1
0.1	16	0.01	4.85	4.12	0.73	219	221	2	<0.05	<0.05		<0.05	<0.05		5.2	4.7	0.5	24.1	23.3	0.8
0.1	24	0.04	4.89	3.89	1.00	218	227	9	<0.05	<0.05		<0.05	<0.05		5.3	4.8	0.5	23.1	23.3	0.2
0.5	9	0.01	4.78	4.19	0.59	196	198	2	<0.05	<0.05		<0.05	<0.05		5.6	4.8	0.8	26.6	25.9	0.7
0.5	16	0.01	4.58	3.85	0.73	314	351	37	<0.05	<0.05		<0.05	<0.05		5.7	4.7	1.0	24.0	23.5	0.5
0.5	24	0.09	4.55	3.70	0.85	287	226	61	<0.05	<0.05		<0.05	0.06		6.0	5.2	0.8	24.1	23.9	0.2
1.0	9	0.005	4.21	4.09	0.12	278	300	22	<0.05	<0.05		<0.05	<0.05		5.2	4.7	0.5	24.7	24.4	0.3
1.0	16	0.01	3.84	3.05	0.79	193	227	34	<0.05	<0.05		<0.05	0.05		6.2	4.8	1.4	25.0	24.3	0.7
1.0	24	0.15	3.05	2.85	0.20	231	178	53	<0.05	0.06		<0.05	0.07		4.6	5.0	0.4	23.3	23.2	0.1
20 minutes																				
0.1	9	0.005	4.22	3.10	1.12	274	290	16	<0.05	<0.05		<0.05	<0.05		5.1	4.2	0.9	24.6	24.1	0.5
0.1	16	0.01	3.99	3.08	0.91	216	265	49	<0.05	<0.05		<0.05	<0.05		6.6	5.5	1.1	25.4	24.7	0.7
0.1	24	0.05	4.72	2.65	2.07	239	348	109	<0.05	<0.05		<0.05	<0.05		4.7	4.8	0.1	25.7	25.3	0.4
0.5	9	0.005	4.21	3.68	0.53	286	86	200	<0.05	<0.05		<0.05	<0.05		4.7	4.9	0.2	25.1	24.7	0.4
0.5	16	0.01	4.46	3.50	0.96	292	233	59	<0.05	<0.05		<0.05	<0.05		4.5	4.8	0.3	24.7	24.2	0.5
0.5	24	0.10	4.61	2.59	2.02	214	318	104	<0.05	<0.05		<0.05	0.06		4.9	5.6	0.7	24.5	24.2	0.3
1.0	9	0.01	4.52	3.92	0.60	238	204	34	<0.05	<0.05		<0.05	0.05		5.8	4.4	1.4	24.1	23.8	0.3
1.0	16	0.01	4.33	3.28	1.05	178	189	11	<0.05	<0.05		<0.05	0.06		4.8	4.3	0.5	23.2	22.9	0.3
1.0	24	0.65	3.56	2.44	1.12	250	327	77	<0.05	0.06		<0.05	0.09		5.4	4.6	0.8	25.3	24.7	0.6
30 minutes																				
0.1	9	0.01	5.13	4.14	0.99	289	328	39	<0.05	<0.05		<0.05	<0.05		5.0	5.2	0.2	24.0	24.1	0.1

0.1	16	0.01	5.58	4.05	1.53	342	334	8	<0.05	<0.05		<0.05	<0.05		5.2	5.3	0.1	24.9	24.0	0.9
0.1	24	0.08	4.17	3.69	0.48	258	393	135	<0.05	<0.05		<0.05	<0.05		4.5	4.9	0.4	24.3	23.9	0.4
0.5	9	0.004	4.39	3.67	0.72	246	211	35	<0.05	<0.05		<0.05	0.06		5.8	5.0	0.8	24.3	24.1	0.2
0.5	16	0.01	4.76	2.89	1.87	116	329	213	<0.05	<0.05		<0.05	0.08		5.2	5.1	0.1	25.0	24.7	0.3
0.5	24	0.24	4.83	2.11	2.72	181	397	216	<0.05	0.07		<0.05	0.12		6.0	4.9	1.1	25.5	25.3	0.2
1.0	9	0.005	4.23	3.83	0.40	193	233	40	<0.05	<0.05		<0.05	0.11		5.0	4.6	0.4	26.1	25.7	0.4
1.0	16	0.01	4.34	3.00	1.34	220	331	111	<0.05	0.08		<0.05	0.12		5.0	4.7	0.3	24.3	24.0	0.3
1.0	24	0.40	4.98	2.28	2.70	229	537	308	<0.05	0.11		<0.05	0.16		6.0	5.2	0.8	24.8	23.9	0.9

Table 6: Titanium/Titanium 920 (Alkaline Electrolysed water)

NaCl concentration (%)	Voltage (V)	Amperage (A)	pH			ORP			Free chlorine			Total chlorine			DO			Temperature		
			Before	After	Diff.	Before	After	Diff.	Before	After	Diff.	Before	After	Diff.	Before	After	Diff.	Before	After	Diff.
10 minutes																				
0.1	9	0.005	4.87	4.73	0.14	210	203	7	<0.05	<0.05		<0.05	<0.05		5.2	4.8	0.4	23.2	23.1	0.1
0.1	16	0.1	4.85	4.87	0.02	219	197	22	<0.05	<0.05		<0.05	<0.05		5.2	4.7	0.5	24.1	23.1	1.0
0.1	24	0.04	4.89	4.97	0.08	218	182	36	<0.05	<0.05		<0.05	<0.05		5.3	4.5	0.8	23.1	23.2	0.1
0.5	9	0.01	4.78	5.98	1.20	196	30	166	<0.05	<0.05		<0.05	<0.05		5.6	4.8	0.8	26.6	26.2	0.4
0.5	16	0.01	4.58	6.49	1.91	314	-13	327	<0.05	<0.05		<0.05	<0.05		5.7	4.1	1.6	24.0	24.0	0.0
0.5	24	0.09	4.55	10.04	5.49	287	-131	418	<0.05	<0.05		<0.05	<0.05		6.0	6.1	0.1	24.1	23.9	0.2
1.0	9	0.005	4.21	4.35	0.14	278	281	3	<0.05	<0.05		<0.05	<0.05		5.2	4.5	0.7	24.7	24.6	0.1
1.0	16	0.01	3.84	4.37	0.53	193	103	90	<0.05	<0.05		<0.05	<0.05		6.2	4.5	1.7	25.0	24.5	0.5
1.0	24	0.15	3.05	5.88	2.83	231	-97	328	<0.05	<0.05		<0.05	0.05		4.6	5.2	0.6	23.3	23.3	0.0
20 minutes																				
0.1	9	0.005	4.22	5.57	1.35	274	41	233	<0.05	<0.05		<0.05	<0.05		5.2	4.8	0.4	23.2	23.1	0.1
0.1	16	0.01	3.99	9.60	5.61	216	-81	297	<0.05	<0.05		<0.05	<0.05		5.2	4.7	0.5	24.1	23.1	1.0
0.1	24	0.05	4.72	10.94	6.22	239	-185	424	<0.05	<0.05		<0.05	<0.05		5.3	4.5	0.8	23.1	23.2	0.1
0.5	9	0.005	4.21	5.25	1.04	286	86	200	<0.05	<0.05		<0.05	<0.05		5.6	4.8	0.8	26.6	26.2	0.4
0.5	16	0.01	4.46	7.29	2.83	292	-63	355	<0.05	<0.05		<0.05	<0.05		5.7	4.1	1.6	24.0	24.0	0.0
0.5	24	0.10	4.61	10.61	6.00	214	-171	385	<0.05	<0.05		<0.05	<0.05		6.0	6.1	0.1	24.1	23.9	0.2
1.0	9	0.01	4.52	5.18	0.66	238	71	167	<0.05	<0.05		<0.05	<0.05		5.2	4.5	0.7	24.7	24.6	0.1
1.0	16	0.01	4.33	6.97	2.64	178	-69	247	<0.05	<0.05		<0.05	0.06		6.2	4.5	1.7	25.0	24.5	0.5
1.0	24	0.65	3.56	11.57	8.01	250	-294	544	<0.05	0.06		<0.05	0.08		4.6	5.2	0.6	23.3	23.3	0.0
30 minutes																				

0.1	9	0.01	5.13	7.13	2.00	289	-89	378	<0.05	<0.05		<0.05	<0.05		5.0	4.8	0.2	24.0	24.1	0.1
0.1	16	0.01	5.58	9.13	3.55	342	-104	446	<0.05	<0.05		<0.05	<0.05		5.2	4.4	0.8	24.9	24.3	0.6
0.1	24	0.08	4.17	10.44	6.27	258	-277	535	<0.05	<0.05		<0.05	<0.05		4.5	4.3	0.2	24.3	23.8	0.5
0.5	9	0.004	4.39	5.49	1.10	246	235	11	<0.05	<0.05		<0.05	<0.05		5.8	5.7	0.1	24.3	24.2	0.1
0.5	16	0.01	4.76	9.74	4.98	116	-122	238	<0.05	<0.05		<0.05	<0.05		5.2	5.7	0.5	25.0	24.8	0.2
0.5	24	0.24	4.83	11.62	6.79	181	-275	456	<0.05	<0.05		<0.05	<0.05		6.0	5.1	0.9	25.5	24.9	0.6
1.0	9	0.005	4.23	6.47	2.24	193	-45	238	<0.05	<0.05		<0.05	0.05		6.0	4.5	1.5	26.1	25.3	0.8
1.0	16	0.01	4.34	9.26	4.92	220	-89	309	<0.05	<0.05		<0.05	0.06		5.0	5.2	0.2	24.3	23.8	0.5
1.0	24	0.40	4.98	11.84	6.86	229	-301	530	<0.05	0.06		<0.05	0.24		6.0	4.8	1.2	24.8	23.9	0.9

Table 7: Titanium/Stainless Steel (Neutral Electrolysed water)

NaCl concentration (%)	Voltage (V)	Amperage (A)	pH			ORP			Free chlorine			Total chlorine			Dissolved Oxygen			Temperature		
			Before	After	Diff.	Before	After	Diff.	Before	After	Diff	Before	After	Diff.	Before	After	Diff.	Before	After	Diff.
10 minutes																				
0.1	9	0.007	5.37	5.15	0.22	344	303	41	<0.05	<0.05		<0.05	<0.05		4.5	3.9	0.6	25.7	25.8	0.1
0.1	16	0.03	5.24	4.17	1.07	174	29	145	<0.05	<0.05		<0.05	<0.05		5.1	4.6	0.5	25.0	23.5	1.5
0.1	24	0.05	9.23	5.14	4.09	244	-156	400	<0.05	<0.05		<0.05	<0.05		4.6	4.3	0.3	25.4	25.1	0.3
0.5	9	0.011	5.35	5.63	0.28	345	22	323	<0.05	<0.05		<0.05	<0.05		5.1	4.8	0.3	26.6	25.8	0.8
0.5	16	0.03	5.23	4.31	0.92	344	132	212	<0.05	<0.05		<0.05	<0.05		6.2	6.0	0.2	25.7	24.9	0.8
0.5	24	0.15	5.18	5.35	0.17	203	68	135	<0.05	<0.05		<0.05	<0.05		5.8	4.7	1.1	24.6	24.6	0.0
1.0	9	0.006	5.21	5.10	0.11	228	260	32	<0.05	<0.05		<0.05	<0.05		5.7	6.0	0.3	24.9	24.1	0.8
1.0	16	0.02	5.36	6.34	0.98	152	121	31	<0.05	<0.05		<0.05	<0.05		5.8	5.9	0.1	25.3	24.8	0.5
1.0	24	0.122	5.26	7.23	1.97	145	-72	217	<0.05	<0.05		<0.05	0.06		5.7	6.0	0.3	25.6	24.3	1.3
20 minutes																				
0.1	9	0.01	5.39	4.80	0.59	112	139	27	<0.05	<0.05		<0.05	<0.05		4.7	4.5	0.2	25.1	25.2	0.1
0.1	16	0.01	5.20	5.45	0.25	172	85	87	<0.05	<0.05		<0.05	<0.05		4.5	5.1	0.6	24.9	24.8	0.1
0.1	24	0.03	5.11	5.27	0.16	204	-70	274	<0.05	<0.05		<0.05	<0.05		4.6	4.2	0.4	23.4	23.7	0.3
0.5	9	0.003	5.07	5.12	0.05	176	221	45	<0.05	<0.05		<0.05	<0.05		4.4	4.0	0.4	23.6	23.7	0.1
0.5	16	0.01	5.13	5.22	0.09	233	212	21	<0.05	<0.05		<0.05	<0.05		5.9	5.6	0.3	24.8	24.5	0.3
0.5	24	0.11	5.09	5.03	0.06	249	-97	346	<0.05	<0.05		<0.05	<0.05		4.0	4.6	0.6	24.8	24.3	0.5
1.0	9	0.01	5.22	4.72	0.50	184	92	92	<0.05	<0.05		<0.05	<0.05		5.9	6.2	0.3	24.5	23.6	0.9
1.0	16	0.01	5.40	5.58	0.18	142	103	39	<0.05	<0.05		<0.05	<0.05		5.9	6.4	0.5	24.6	23.9	0.7
1.0	24	0.268	5.11	5.10	0.01	163	28	135	<0.05	<0.05		<0.05	0.08		5.9	6.3	0.4	25.6	24.7	0.9
30 minutes																				
0.1	9	0.01	5.31	4.58	0.73	160	40	120	<0.05	<0.05		<0.05	<0.05		5.0	4.5	0.5	25.4	25.1	0.3

0.1	16	0.01	5.29	5.44	0.15	167	-115	282	<0.05	<0.05		<0.05	<0.05		4.3	4.5	0.2	25.7	25.2	0.5
0.1	24	0.03	5.19	4.43	0.76	178	-51	229	<0.05	<0.05		<0.05	<0.05		5.7	4.3	1.4	24.1	23.3	0.8
0.5	9	0.01	5.24	5.74	0.50	171	-73	244	<0.05	<0.05		<0.05	<0.05		4.9	5.6	0.7	26.4	25.5	0.9
0.5	16	0.01	5.32	5.81	0.49	204	-76	280	<0.05	<0.05		<0.05	<0.05		5.1	5.7	0.6	27.3	26.3	1.0
0.5	24	0.07	5.08	5.94	0.86	211	-181	392	<0.05	0.58		<0.05	0.63		4.6	4.8	0.2	23.9	23.2	0.7
1.0	9	0.009	4.91	4.34	0.57	196	79	117	<0.05	<0.05		<0.05	<0.05		6.4	5.9	0.5	24.3	23.4	0.9
1.0	16	0.014	5.23	6.45	1.22	117	-61	178	<0.05	<0.05		<0.05	<0.05		6.0	5.8	0.2	25.4	24.5	0.9
1.0	24	0.81	5.27	5.23	0.04	260	-78	338	<0.05	<0.05		<0.05	0.13		5.9	6.1	0.2	26.5	25.8	0.7

Table 8: Titanium/Silver (Neutral Electrolysed water)

NaCl concentration (%)	Voltage (V)	Amperage (A)	pH			ORP			Free chlorine			Total chlorine			Dissolved Oxygen			Temperature		
			Before	After	Diff.	Before	After	Diff.	Before	After	Diff.	Before	After	Diff.	Before	After	Diff.	Before	After	Diff.
10 minutes																				
0.1	9	0.006	5.39	5.28	0.11	337	358	21	<0.05	<0.05		<0.05	<0.05		6.0	4.8	1.2	28.0	26.8	1.2
0.1	16	0.010	5.28	5.23	0.05	227	161	66	<0.05	<0.05		<0.05	<0.05		6.1	5.5	0.6	25.4	24.7	0.7
0.1	24	0.02	5.41	5.95	0.54	190	-33	223	<0.05	<0.05		<0.05	<0.05		4.6	4.8	0.2	24.4	24.2	0.2
0.5	9	0.006	5.49	5.50	0.01	265	302	37	<0.05	<0.05		<0.05	<0.05		5.2	5.8	0.6	25.3	24.4	0.9
0.5	16	0.010	5.35	5.80	0.45	193	98	95	<0.05	<0.05		<0.05	<0.05		6.0	5.8	0.2	24.6	24.0	0.6
0.5	24	0.03	5.59	5.60	0.01	172	-4	176	<0.05	<0.05		<0.05	<0.05		5.3	5.1	0.2	24.5	24.1	0.4
1.0	9	0.008	5.03	5.51	0.48	200	197	3	<0.05	<0.05		<0.05	<0.05		6.2	6.2	0	24.5	24.5	0
1.0	16	0.017	5.35	5.98	0.63	210	14	196	<0.05	<0.05		<0.05	<0.05		6.2	5.7	0.5	24.5	24.5	0
1.0	24	0.10	5.35	4.81	0.54	264	-72	336	<0.05	0.08		<0.05	0.15		5.7	5.2	0.5	27.7	26.9	0.8
20 minutes																				
0.1	9	0.01	5.51	4.72	0.79	202	171	31	<0.05	<0.05		<0.05	<0.05		5.9	5.8	0.1	24.5	23.8	0.7
0.1	16	0.007	5.51	5.11	0.4	348	54	294	<0.05	<0.05		<0.05	<0.05		5.3	5.6	0.3	25.5	25.3	0.2
0.1	24	0.04	5.40	9.06	3.66	139	-182	321	<0.05	<0.05		<0.05	<0.05		4.5	5.3	0.8	25.2	24.6	0.6
0.5	9	0.010	5.36	5.84	0.48	328	327	1	<0.05	<0.05		<0.05	<0.05		5.6	5.3	0.3	25.7	24.3	1.4
0.5	16	0.008	5.40	4.72	0.68	240	295	55	<0.05	<0.05		<0.05	<0.05		5.6	5.5	0.1	25.6	24.2	1.4
0.5	24	0.032	5.42	7.07	1.65	196	-158	354	<0.05	<0.05		<0.05	<0.05		4.6	4.5	0.1	26.3	25.3	1
1.0	9	0.008	5.43	5.81	0.38	211	131	80	<0.05	<0.05		<0.05	<0.05		5.5	5.5	0	24.2	24.1	0.1
1.0	16	0.014	5.38	4.89	0.49	234	19	215	<0.05	<0.05		<0.05	<0.05		5.4	5.7	0.3	24.2	23.2	1
1.0	24	0.037	5.34	4.44	0.9	96	287	191	<0.05	<0.05		<0.05	0.08		4.7	5.6	0.9	27.5	25.1	2.4
30 minutes																				

0.1	9	0.006	5.52	4.89	0.63	192	158	34	<0.05	<0.05		<0.05	<0.05		5.2	5.3	0.1	25.9	25.6	0.3
0.1	16	0.008	5.59	7.69	2.1	153	-78	231	<0.05	<0.05		<0.05	<0.05		5.1	5.0	0.1	26.9	26.2	0.7
0.1	24	0.012	5.29	5.38	0.09	86	0	86	<0.05	<0.05		<0.05	<0.05		5.5	5.1	0.4	27.3	25.7	1.6
0.5	9	0.01	6.66	6.38	0.28	159	155	4	<0.05	<0.05		<0.05	<0.05		5.6	5.8	0.2	24.7	24.4	0.3
0.5	16	0.01	5.49	9.03	3.54	172	-79	251	<0.05	<0.05		<0.05	<0.05		5.8	5.7	0.1	24.5	24.7	0.2
0.5	24	0.33	5.33	8.47	3.14	349	-243	592	<0.05	0.58		<0.05	0.63		5.3	5.4	0.1	27.7	25.9	1.8
1.0	9	0.010	5.32	5.43	0.11	201	89	112	<0.05	<0.05		<0.05	<0.05		5.4	5.7	0.3	24.5	23.6	0.9
1.0	16	0.012	5.38	6.23	0.85	141	-7	148	<0.05	<0.05		<0.05	<0.05		5.3	5.5	0.2	25.8	24.8	1
1.0	24	0.76	5.37	5.50	0.13	168	-253	421	<0.05	0.07		<0.05	0.17		4.6	5.0	0.4	27.8	26.7	1.1

Table 9: Titanium/Titanium 920 (Neutral Electrolysed water)

NaCl concentration (%)	Voltage (V)	Amperage (A)	pH			ORP			Free chlorine			Total chlorine			Dissolved Oxygen			Temperature		
			Before	After	Diff.	Before	After	Diff.	Before	After	Diff	Before	After	Diff.	Before	After	Diff.	Before	After	Diff.
10 minutes																				
0.1	9	0.01	5.27	4.85	0.42	321	203	118	<0.05	<0.05		<0.05	<0.05		4.8	4.6	0.2	25.2	24.2	1.0
0.1	16	0.01	4.82	4.80	0.02	238	114	124	<0.05	<0.05		<0.05	<0.05		4.5	4.6	0.1	27.4	27.0	0.4
0.1	24	0.03	4.94	5.20	0.26	162	12	150	<0.05	<0.05		<0.05	<0.05		4.3	5.5	1.2	28.3	27.4	0.9
0.5	9	0.01	4.99	4.88	0.11	282	167	115	<0.05	<0.05		<0.05	<0.05		4.5	4.6	0.1	26.0	25.3	0.7
0.5	16	0.01	5.06	5.35	0.29	339	66	273	<0.05	<0.05		<0.05	<0.05		4.2	4.7	0.5	26.5	25.8	0.7
0.5	24	0.09	5.05	4.63	0.42	215	38	177	<0.05	<0.05		<0.05	<0.05		4.8	5.1	0.3	23.5	22.8	0.7
1.0	9	0.01	5.19	5.17	0.02	232	250	18	<0.05	<0.05		<0.05	<0.05		5.3	4.3	1.0	24.1	23.7	0.4
1.0	16	0.01	5.10	5.07	0.03	261	228	33	<0.05	<0.05		<0.05	0.06		5.1	4.2	0.9	23.2	22.9	0.3
1.0	24	0.08	5.07	5.00	0.07	240	79	161	<0.05	0.05		<0.05	0.09		4.4	4.6	0.2	23.3	23.1	0.2
20 minutes																				
0.1	9	0.005	5.00	5.42	0.42	318	197	121	<0.05	<0.05		<0.05	<0.05		4.3	4.6	0.3	25.1	24.8	0.3
0.1	16	0.01	4.95	5.69	0.74	344	-8	352	<0.05	<0.05		<0.05	<0.05		4.2	4.3	0.1	26.6	26.9	0.3
0.1	24	0.04	5.04	4.13	0.91	309	29	280	<0.05	<0.05		<0.05	0.06		4.1	5.5	. 1.4	25.6	25.3	0.3
0.5	9	0.005	4.92	5.09	0.17	355	146	209	<0.05	<0.05		<0.05	<0.05		4.2	4.0	0.2	26.5	25.9	0.6
0.5	16	0.01	5.01	5.00	0.01	318	47	271	<0.05	<0.05		<0.05	0.07		4.3	4.8	0.5	26.4	26.0	0.4
0.5	24	0.13	5.05	8.22	3.17	204	-121	325	<0.05	0.06		<0.05	0.09		4.5	5.5	1.0	25.4	24.6	0.8
1.0	9	0.01	4.35	5.01	0.66	216	42	174	<0.05	<0.05		<0.05	0.06		4.6	4.0	0.6	26.1	25.5	0.6
1.0	16	0.01	4.71	4.94	0.23	269	26	243	<0.05	<0.05		<0.05	0.07		5.0	4.5	0.5	25.9	24.8	1.1
1.0	24	0.16	4.99	4.24	0.75	238	-52	290	<0.05	0.08		<0.05	0.12		5.2	4.6	0.6	24.6	24.0	0.6
30 minutes																				
0.1	9	0.005	5.18	4.21	0.97	323	118	205	<0.05	<0.05		<0.05	<0.05		6.0	5.6	0.4	23.7	23.5	0.2

0.1	16	0.01	5.24	3.65	1.59	358	51	307	<0.05	<0.05		<0.05	<0.05		6.1	5.7	0.4	24.7	24.3	0.4
0.1	24	0.12	5.14	10.09	4.95	253	-180	433	<0.05	<0.05		<0.05	0.06		5.1	4.8	0.3	25.6	25.2	0.4
0.5	9	0.005	4.89	4.59	0.3	303	258	45	<0.05	<0.05		<0.05	0.07		4.6	5.3	0.7	25.9	25.4	0.5
0.5	16	0.01	4.88	3.57	1.31	198	42	156	<0.05	<0.05		<0.05	0.08		5.0	5.2	0.2	24.6	24.2	0.4
0.5	24	0.25	4.93	5.95	1.02	356	-147	503	<0.05	0.09		<0.05	0.11		4.5	4.6	0.1	24.9	25.0	0.1
1.0	9	0.005	4.92	4.78	0.14	318	169	149	<0.05	0.05		<0.05	0.09		4.5	4.6	0.1	25.4	25.0	0.4
1.0	16	0.01	5.05	4.64	0.41	233	59	174	<0.05	0.08		<0.05	0.11		5.1	4.6	0.5	26.7	25.2	1.5
1.0	24	0.50	5.01	9.8	4.79	216	-136	352	<0.05	0.12		<0.05	0.15		4.5	5.4	0.9	25.7	25.4	0.3