DEVELOPMENT OF ELECTROCOAGULATION CELL BY USING DIFFERENT TYPES OF ELECTRODE MATERIALS TO TREAT RESTAURANT WASTEWATER

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CHONG LI PING

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ABSTRAK

Sel elektrokoagulasi (EC) adalah teknologi untuk mengurangkan bahan pencemar dari air sisa yang melibatkan arus elektrik ke dalam medium berair degan menggunakan elektrod. Penghasilan EC dengan menggunakan pelbagai jenis bahan elektrod untuk merawat air kumbahan restoran diselidik dalam kajian ini. Dua jenis bahan elektrod digunakan seperti Aluminium (Al) dan Besi (Fe) untuk menentukan keefisienan penyingkiran permintaan oksigen biologi (BOD), permintaan oksigen kimia (COD) dan jumlah pepejal terampai (TSS). Empat eksperimen telah dijalankan dengan menggunakan kombinasi bahan elektrod yang berbeza di anoda dan katod iaitu Al-Al, Fe-Fe, Al-Fe dan Fe-Al. Parameter operasi seperti jarak antara elektrod, tempoh rawatan, arus telah ditetapkan pada 10 mm, 120 minit dan 3 A. Keputusan penyingkiran tertinggi untuk BOD (98%), COD (91.4%) dan TSS (86.9%) telah diperolehi oleh Al-Fe di antara empat jenis elektrod. Sementara itu, pasangan elektrod terendah dicatatkan oleh Al-Al ialah 70.9%, 85.7% dan 64.4% untuk BOD, COD dan TSS. Selain itu, elektrod Fe-Al menunjukkan keputussan pengikiran 80.7%, 96.7% dan 63.0% untuk BOD, COD dan TSS. Akhir sekali, elektrod Fe-Fe mencapai penyingkiran keefisienan 80.6%, 95.7% dan 61.5% BOD, COD dan TSS. Hasil ini dapat dijelaskan oleh proses yang berlaku di anoda dan katod. Al memainlan peranan di anod kerana ia mengeluarkan ion trivalen (Al^{3+}) berbanding dengan elektrod besi yang menghasilkan ion divalent (Fe^{2+}). Cas positif yang tinggi mempunyai keupayaan yang lebih tinggi untuk mengurangkan kestabilan koloid. Selain itu, Fe lebih baik di katod kerana ia melepaskan banyak buih bersize kecil yang membantu dalam menghilangkan pepejal terampai dan membentuk pemberbukuan. Jumlah penghancuran Al adalah 0.102 g manakala Fe mencatatkan 0.801 g di mana Al melepaskan lebih banyak ion trivalen untuk membekukan pencemar dalam air kumbahan restoran. Keputusan eksperimen menunjukkan penyingkiran BOD, COD dan TSS yang efektif melalui cara EC dengan menggunakan elektrod Al dan Fe.

ABSTRACT

Electrocoagulation cell (EC) is a technology to remove pollutants from wastewater which involve electric current into an aqueous medium using electrode. Development of EC by using different types of electrode materials to treat restaurant wastewater was investigated in this study. Two types of electrodes materials were used such as Aluminums (Al) and Iron (Fe) to determine the removal efficiency of biological oxygen demand (BOD), chemical oxygen demand (COD) and total suspended solids (TSS). Four experiments were run out by using different combination of electrode materials at anode and cathode which were Al-Al, Fe-Fe, Al-Fe and Fe-Al. The operating parameters such as inter-electrode distance, treatment duration, current intensity were fixed at 10mm, 120 minutes and 3A respectively. The highest removal for BOD (98%), COD (91.4%) and TSS (86.9%) was obtained by Al-Fe among four electrode types. Meanwhile, the lowest electrode pairs were recorded by Al-Al with a value of 70.9%, 85.7% and 64.4% for BOD, COD and TSS respectively. Besides, Fe-Al electrodes showed a result of 80.7%, 96.7% and 63.0% of BOD, COD and TSS removal efficiency respectively. Last but not least, Fe-Fe electrodes achieved 80.6%, 95.7% and 61.5% efficiency removal of BOD, COD and TSS. This result can be explained by process occurred at anode and cathode. Al performed good at anode as it released trivalent ion (Al^{3+}) instead of divalent ion (Fe^{2+}) by iron electrode. Higher positive charge had higher ability to destabilise the colloids. While, Fe was better at cathode because it released small size but large amount of bubbles which helped in removing suspended solids and formed flocculation. The amount of Al dissolution was 0.102 g while Fe recorded 0.801 g which meant Al released more trivalent ion to coagulate the pollutant in restaurant wastewater. The experiments result showed efficient removal of BOD, COD and TSS by EC with Al and Fe electrodes.

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C	Concentration BOD, COD and TSS after treatment, mg/L
C_o	Concentration of BOD, COD and TSS before treatment, mg/L
F	Faraday constant (96485.3 C mol^{-1})
I	Current, A
M	Mass of anode dissolved, g
T	Time of operation, s
Z	Number of electrons donates in anodic solution process per mole of metal

LIST OF ABBREVIATIONS

AC	Alternating power supply
AD	Anaerobic digestion
Al	Aluminium
Aq	Aqueous
BOD	Biological oxygen demand
BP	Bipolar
COD	Chemical oxygen demand
DAF	Dissolved air flotation
DC	Direct current
EC	Electrocoagulation
Fe	Iron
FOG	Fats, oils and grease
G	Gas
HCl	Hydrochloric acid
IC	Internal combustion
MBAS	Methylene blue active substance
O&G	Oil and grease
POME	Palm Oil Mill Effluent
RDE	Restaurant dishwasher effluent
S	Solid
STE	Septic tank effluent
TOC	Total organic carbon
TSS	Total suspended solid

CHAPTER 1

INTRODUCTION

1.1 Background of Study

One of the most pressing challenges in the 21st century is providing sufficient clean water supply that is free from pollutants. In terms of humans, recent estimates reveal that there are 884 million people throughout the world who do not have access to clean and healthy sources of drinking water (Kristen E. Gibson, 2011). Poor access to clean water not only creates logistical problems for the people, but also makes them more disposed to many water borne diseases. Water is clearly one of the most basic of human needs, crucial to sustain all of life of human, animal and plant. Each person on Earth needs at least 20 to 50 litres of clean and safe water a day for drinking, cooking, and simply keeping themselves clean (National Academy of Sciences, 2007). Just like humans, plants and animals require water that is clean and moderately pure because they cannot survive if water is loaded with toxic chemical or harmful microorganisms.

Wastewater refers to water that has been used. It originates mainly from domestic, industrial, groundwater, and meteorological sources, and commonly referred to as domestic sewage, industrial waste, infiltration, and storm-water drainage. Wastewater from restaurants and other commercial food service differs significantly from residential wastewater. In addition to higher flow volumes during busy periods, and usually-higher temperatures, restaurant wastewater is normally higher in strength than residential wastewater. The direct discharge of wastewater from restaurants down the drain is a huge extra burden to the municipal wastewater collection and treatment works. The oil and grease contained in the wastewater amassed and foul the sewer system and produce an unpleasant odour (Chen et al., 2000).

Basically, restaurant wastewater treatment facilities must be highly effective in eliminating biological oxygen demand (BOD), chemical oxygen demand (COD) and total suspended solid (TSS). Low capital and operating costs are important because profit borders of most restaurants are small. In addition, the technology has to be simple so that it can be operated easily. Conventional treatment that can be used to treat restaurant wastewater are physical, chemical or biological treatment. Conventional biological processes are not suitable due to the requirement of large space, long residence time and skilled technicians. Chemical coagulation is not practicable because of the low efficiency in removing light and finely dispersed oil particles and possible contamination of foods by chemicals. The G-bag approach, which uses a bag of absorbent to capture the pollutants and degrade the pollutants with the immobilized microorganisms on the absorbent, seems to be a good alternative only if the system can be designed as simple and free from fouling (Chen et al., 2000).

Electrocoagulation (EC) has been suggested as an advanced alternative in pollutant removal of restaurant wastewaters. Electrocoagulation is a treatment process involve electric current into an aqueous medium in an electrochemical cell using an electrode (Malakangouda et al, 2016). At this point, the process has attracted a great deal of attention in treating various wastewaters because of its versatility and environmental compatibility (Ozyonar & Karagozoglu, 2011). The electrocoagulation process also is a simple equipment, easy operation, a shortened reactive retention time, no chemical additions, and decreased amount of precipitate or sludge, which sediments rapidly (Ozyonar & Karagozoglu, 2011).

Electrocoagulation was first suggested by Vik et al. describing a sewage treatment plant in London built in 1889 where electrochemical treatment was employed via mixing the domestic wastewater with saline seawater. In 1909, J.T. Harries received a patent for wastewater treatment by electrolysis using sacrificial aluminium and iron anodes in the United States (Vik et al., 1984). (Matteson et al., 1995) described the ‘Electronic Coagulator’, which electrochemically dissolved aluminium from the anode into the reaction solution that cooperated with the hydroxyl ions produced at the cathode to form aluminium hydroxide. The hydroxides flocculated and coagulated the suspended solids, purifying the polluted water. A similar process was used in Great Britain in 1956 (Matteson et al., 1995), in which iron electrodes were used to treat polluted river water.

Electrocoagulation has been tested successfully to treat potable water (Vik et al., 1984), textile wastewater (Demirci et al., 2015), slaughterhouse wastewater (Widiasa & Johari, 2010), simulated quick service restaurant wastewater et al., 2014), restaurant wastewater (Chen et al., 2000) and tannery wastewater (Malakangouda et al., 2016). This process is characterized by a fast rate of pollutant removal, compact size of the equipment, simplicity in operation, and low capital and operating costs. Besides, it is more effective in treating wastewaters containing small and light suspended particles, such as oily restaurant wastewater, because of the additional electro-flotation effect. It is estimated that the electrocoagulation would be an ideal choice for treating restaurant wastewaters. Hence, the electrode factor is observe to study the effectiveness of the electrocoagulation process in order to reduce the concentration in retention of time.

1.2 Problem Statement

Most of the Malaysia's population tend to follow western lifestyle in which results in consumers are willing to dine at restaurants instead of dining at home (Dong et al., 2016). The amount of restaurant waste apparently increases with the increasing number of restaurants in town. The owners of restaurants discharge the waste directly into the drains near to their restaurants. Therefore, the rivers nearby are polluted by the restaurants waste. Department of Statistic Malaysia show that food service establishments (FSE) alone accounted for 192, 710 sources of pollution identified in 2012. The main pollutants in rivers are biological oxygen demand (BOD), chemical oxygen demand (COD) and total suspended solids (TSS). Moreover, restaurant wastewater contains high BOD, COD and TSS which pose serious harm to environment and human health. Next, TSS reduces water turbidity and light penetration. As a result, photosynthetic process of micro plants in rivers is reduced. Not only that, it also will lead to bad odour but potential pipe failure. Besides, high BOD and COD concentration affect the deoxygenating which threaten the aquatic life and limit the clean water source (Singh et al., 2014).

In addition, the pollutants can be neither simply treated conventionally nor decomposed biologically due to their consistency. Besides, conventional treatment of restaurant wastewater takes longer time to be treated. Other than conventional biological treatment, chemical coagulation settlement also not practicable because it is not efficient in removing light and finely dispersed oil particles by chemicals (Xu et al., 2004). However, among all the methods of treating restaurant wastewater, electrocoagulation is better and effective method to treat restaurant wastewater.

Electrocoagulation is characterized by a fast rate of pollutant removal, compact size of equipment, simplicity in operation, and low capital and operating costs (Xu et al., 2004). In order to maximize the effectiveness of electrocoagulation on restaurant wastewater, operating parameter and electrode factor play an important role. Many researches on electrocoagulation on restaurant wastewater have been reported, however the mechanism are not yet clearly understood because it is physical system and chemical complex (Dura, 2013). Therefore, electrode factors such as electrode materials are studied to achieve higher effectiveness of pollutant removal. Different types of electrode materials have different rate of dissolution that can affect the oxidation and reduction rate.

1.3 Objectives

The main objective of this study is to investigate the efficiency of electrocoagulation by varying the electrode materials at anode and cathode to remove BOD, COD and TSS from restaurant wastewater. While, the specific objectives are:

1. To determine the effect of aluminium (Al) electrodes at both anode and cathode to treat restaurant wastewater by using electrocoagulation method.
2. To study the effect of iron (Fe) electrodes at both anode and cathode treat restaurant wastewater by using electrocoagulation method.
3. To investigate the effect of composite electrodes Al-Fe and Fe-Al treat restaurant wastewater by using electrocoagulation method.

1.4 Scope of the Study

The scope of this project is to develop the electrocoagulation cell that studies the effects of the electrode material of the treatment of the restaurant wastewater. The electrode material may affect the capabilities of the electrocoagulation cell in purging the BOD, COD, TSS in restaurant wastewater. The restaurant wastewater contains a high concentration of BOD, COD and TSS. Therefore, the electrode material is considered to study the effectiveness of the electrocoagulation cell in order to reduce the concentration of the contaminants in short amounts of time. Electrocoagulation is the method that can be proposed for the treatment of restaurant wastewater because of the restaurant does not have the proper method that can treat their wastewater.

The restaurant wastewater sample used was taken from the Malay food premise near Teluk Cempedak, Pahang. Firstly, 4 litre of sample were collected using a plastic bottle and immediately kept in chiller under 4 ^{o}C in laboratory. The experiment was carried out by using 1000 mL of the beaker, the electrodes size of 30 mm x 60 mm with the thickness of 3 mm and the electrodes were clamped by wire to connect the electrode to the power DC supply. The inter-electrode distance is 10 mm and the treatment time was 120 minutes for each type of electrode materials with current output of 3 A. The standard methods were used to measure the concentration amount of BOD, COD, and TSS in restaurant wastewater before and after treatment. The removal efficiency of the pollutant was calculated by using removal percentage formula. The graph of removal percentage versus time was plotted for each pollutant based on the types of electrode materials.

The materials that use in this study were Al and Fe and also the composite electrode of Al-Fe (anode-cathode) and Fe-Al (anode-cathode). From other studies about electrode materials, there is no evaluation that considers the effectiveness of composite electrode (Fe-Al) for the treatment of wastewater in electrocoagulation process. The experimental for this electrode factor same as the stated methodology. Each of the materials will be studied in the effectiveness to reduce the concentration of BOD, COD and TSS over time. The highest removal percentages of the material used are the best materials in electrocoagulation process in removal BOD, COD and TSS in restaurant wastewater.

1.5 Significance of the Study

The finding of this study will improve the efficiency of the electrocoagulation cell on removing BOD, COD and TSS to protect the community, bring benefit to industry sector and contribute to education.

This study will show the effectiveness of electrocoagulation in the removal of the oil and grease because it is the main contaminant in restaurant wastewater. If the pollutants are left untreated, it will cause to negative effects to human being. Health risks that threaten human being are included typhoid, dysentery, diarrhoea, vomiting, and mal-absorption (S. Fattal et al, 1991). Moreover, high content of BOD discharge into river will cause lethal for fish and many aquatic insects because it enhances bacteria growth which consume the oxygen level in rivers.

In term of industry beneficial, electrocoagulation is thought to be promising treatment technology and cost-effective solution for sustainable wastewater management in the future. Besides, electrocoagulation will be more important to provide a deeper insight into pollutant removal mechanism. Electrocoagulation has its value to various industries as it not only treats domestic wastewater but also industry wastewater. For example, almond industry has treated their wastewater by electrocoagulation successfully. They has proven that problem of high contaminants wastewater which has that is not suitable to be disposed directly in sewage system can be solved by transferring this technology into industry (Valero et al., 2011).

Meanwhile, in term of education, this study is important to provide information and reference about efficiency of electrode factor on electrocoagulation to researchers. The methods and result can be used as guideline and direction to improve further studies on electrocoagulation. Other than that, this study is significant in supporting and proving the truth by carried out the experiment and getting real data analysis. Thus, the combination of the best electrode factor will create the better electrocoagulation cell in the treatment of restaurant wastewater and became the alternative way of the wastewater treatment at the restaurant.

CHAPTER 2

LITERATURE REVIEW

2.1 Restaurant Wastewater

Wastewater from restaurants and other commercial food service facilities vary significantly from domestic wastewater because of greater surge volumes during busy periods and normally higher temperature (Klamklang, 2007). Restaurant wastewater is water that has been used for cleaning meats, rice and vegetables, washing dishes and cooking tools, or cleaning the floor and rag (Chen et al., 2000). The discharge is usually full with organic matters from the leftovers of food and soup which are made of oily flavourings such as spice, soy sauce, seasoning, and others. This kind of wastewater is characterized as high content of COD, SS, BOD and detergent (Lesikar et al., 2002).

Dissimilar most of the developed countries where the restaurant effluent is discharged into filthy drains leading to public sewage treatment plants, the effluent produced by restaurant is mostly discharged into storm drains without proper on-site treatment process (S. Zulaikha, 2014). This situation becomes bad with the lack of awareness by the general public in particular restaurant owner of the wastewater management issues. Therefore, before discharging restaurant wastewater must be pre-treated on-site. Furthermore, wastewater effluent is no longer seen as something to just dispose of, it is now increasingly observed as a dependable water source through human consumption, irrigation, and groundwater recharge with water scarcity occurring globally in the coming decades (Mark A. Shannon, 2008). Hence, much firmer water recovery requirements need to be fulfilled for the reuse of restaurant wastewater. Due to the limitation of space in restaurants, localized treatment facilities should be compact and easy to install and operate (L. Wang, 2007).

2.2 Wastewater Treatment Process

Wastewater treatment involves of applying recognised technology to improve the quality of a wastewater. Usually wastewater treatment will involve collecting the wastewater in a central, segregated location and subjecting the wastewater to various treatment processes. Most often, since large volumes of wastewater are involved, treatment processes are carried out on continuously flowing wastewaters or open systems rather than as batch or a series of periodic treatment processes in which treatment is carried out on parcels or batches of wastewaters (Hung Yung-tse, 2013). While most wastewater treatment processes are continuous flow, certain operations, such as vacuum filtration, involving as it does, storage of sludge, addition of chemicals, filtration and removal or disposal of the treated sludge, are routinely handled as periodic batch operations (Suneetha, 2012). Wastewater treatment can be organized or categorized by the nature of the treatment process operation being used such as physical, chemical or biological treatment (Suneetha, 2012).

2.2.1 Physical treatment

Physical method of wastewater treatment achieve elimination of substances by use of occurring forces, such as gravity, electrical attraction, and van der Waal forces, as well as by use of physical fences (Klamklang, 2007). In general, the appliances involved in physical treatment do not change the chemical structure of the target substances. In some cases, as in vaporization, physical state is changed and often dispersed substances are caused to agglomerate, as happens during filtration. Physical methods of wastewater treatment include sedimentation, flotation, and adsorption, as well as obstacles such as bar racks, screens, deep bed filters, and membranes (Klamklang, 2007). Physical water treatment typically consists of filtration techniques that involve the use of screens, sand filtration or cross flow filtration membranes. Screens are typically used as a pre-treatment method to remove larger suspended material. Meanwhile, sand and/or multimedia filtration frequently used to filter suspended solids. Smaller suspended solids and dissolved solids are often able to pass through these filters, requiring secondary filtration. Membrane filtration used to utilizes barrier (microfiltration, ultrafiltration) or semipermeable (nano or reverse osmosis) membranes to remove suspended solids and total dissolved solids, respectively (Klamklang, 2007). The disadvantages of this treatment are high maintenance costs and high costs of sludge handling than electrocoagulation process.

2.2.1.1 Sedimentation

Sedimentation is employed for the removal of suspended solids from restaurant wastewaters. The process can be measured in the three basic classifications, such as discrete, flocculent and zone settling depending on the nature of the solids present in the suspension. The main purpose of primary sedimentation is to decrease the organic load on the secondary stage itself (thus extending its overall capacity by reducing the retention time), and produce a homogeneous and solid-free wastewater suitable for biological treatment and a sludge flux that can be separately treated or processed. The main role of the primary settler is to eliminate solid particles to avoid the threat of early clogging of the support media of the secondary reactor.

There are also cases where primary settlement is present as the only (partial) treatment. In this case, sometimes accepted for very small treatment plants, the settler is coupled with a tank for storing and stabilizing the separated sludge (Renato I, 2011). Primary settlers are usually equipped with mechanically driven scrapers that continually drive the collected sludge towards a hopper in the base of the tank, and the floating material to a skimmer on the surface from where they can be pumped to further sludge treatment stages.

As biological treatment usually includes a further sedimentation stage (the secondary clarifier), primary sedimentation is omitted in some cases. Specifically, the activated sludge process, because of its relative insensitivity to clogging, does not strictly require primary sedimentation, and in the case of biological nitrogen and/or phosphorous removal enhancements, primary settling may even prove a disadvantage (Renato I, 2011). Although, the treatment is relatively low capital cost, the process required high maintenance costs and high costs of sludge handling.

2.2.1.2 Flotation

Flotation is used for the removal of suspended solids, oil and grease from the wastewaters and for the separation and concentration of sludge. The waste flow of a portion of clarified effluent is pressurized to 3.4-4.8 atm in the presence of sufficient air to approach saturation (Eckenfelder, 1997). When this pressurized air-liquid mixture released to atmospheric pressure in the floatation unit, minute air bubbles are released from the solution. The sludge flocs, suspended solids or oil globules are floated by these minute air bubbles, which attach themselves to and became in the floc particles. The air-solids mixture rises to the surface, where it is skimmed off. The clarified liquid is removed from the bottom of the flotation unit at this time a portion of the effluent may be recycled back to the pressure chamber. When flocculent sludge are to be clarified, pressurized recycle will usually yield a superior effluent quality since the flocs are not subjected to shearing stress through the pumps and pressurizing system (Eckenfelder, 1997).

Restaurant dishwashers consume a large amount of fresh water and produce significant amounts oily wastewater with high strength that may cause serious problems when discharged into the drain. From a busy upscale restaurant an analysis of restaurant dishwasher effluent (RDE) identified high levels COD, and BOD, but low levels of nitrogen and phosphorus (Wayne C, 2014). In this study, RDE was treated using an internationally original chemical dissolved air flotation (chemical DAF) system. The chemical DAF system was considered so that coagulation, flocculation, and flotation processes could be carried out within the same reactor (Wayne C, 2014). The treatment system is therefore small and compact and suitable for use in restaurants where space is limited. The treatment performance of the chemical DAF was calculated by determining optimal process conditions, contaminant removal efficiencies, and residual contaminant concentrations. The result showed that removal efficiencies for TSS, BOD, and COD could be achieved under optimal process conditions, respectively. But, the maintenance costs and costs of sludge handling is high.

2.2.2 Biological treatment

The biological processes in treatment plants are carried out by a much differentiated group of organisms. It is possible roughly to list which species are existent as it shows that the fauna in a treatment plant is very dependent on the external conditions (Mogens Henze, 2013). In the biochemical decomposition of wastewaters, these methods use microorganisms which are bacteria to stable end products. More microorganisms, or sludge are formed and a lot of the waste is transformed to water, carbon dioxide and other end products.

Generally, biological treatment methods can be divided into aerobic and anaerobic methods, based on availability of dissolved oxygen. The purpose of wastewater treatment is generally to remove from the wastewater enough solids to permit the remainder to be discharged to a receiving water without interfering with its best or proper use (Iyyanki V. Muralikrishna, 2017). The solids which are removed are primarily organic but may also include inorganic solids. Treatment must also be provided for the solids and liquids which are removed as sludge. Finally, treatment to control odors, to retard biological activity, or destroy pathogenic organisms may also be needed. All organisms in the biological treatment plant must necessarily have their origins from the outside that is, they come from the wastewaters, from the air, the soil or from the animals which live close to the plant. An essential part of individual organisms has grown in the plant itself. The two main types of biological treatment plants are activated sludge and biofilters treatment plants (Mogens Henze, 2013). Conventional biological processes are eliminated due to the requirement of large space and skilled technicians.

2.2.2.1 Anaerobic digestion

Anaerobic digestion (AD) is a process that employs a consortium of facultative and obligate anaerobic microorganisms to oxidise biodegradable organic materials in the absence of molecular oxygen and produce biogas, mainly methane and carbon dioxide (Fayyaz A S, 2014). As one of the most cost-effective waste and wastewater treatment technologies, AD has been used to treat a wide range of wastes, including municipal solid waste (MSW) and municipal sewage sludge, agriculture wastes and manures, and organic industrial wastes.

The grease wastewater contained in restaurant interceptors contain organic material in the form of fats, oils, greases, carbohydrates, sugars and other organic solids that can be used to generate methane gas through anaerobic digestion. The bacteria in the digester that metabolize these organic materials create a waste product of methane gas. This methane gas can then be collected from the digester and compressed to serve as a fuel for fuel cells, internal combustion (IC) engines that operate electrical generators, micro turbines, and gas turbines. Problems have arisen with the disposal of the grease interceptor wastewater. Although anaerobic treatment of restaurant wastewater has been proposed in removing oil and grease from wastewater, the cost of disposal continues to rise; the sites for disposal continue to diminish; and illegal disposal of these wastes is increasing cause public health problems (Fayyaz A S, 2014).

2.2.2.2 Activated sludge treatment

The activated sludge process is a suspended growth biological treatment process in which a mixture of biological sludge and wastewater, composed of microorganisms, is agitated and aerated. Air is provided through the use of diffused or mechanical aeration. The microorganisms are mixed with the organic compounds and use this organic material as their food source. As the microorganisms grow and are varied by agitation of the air, the individual organisms clump together (a process known as flocculation) to produce a biological floc, an active mass of microbes called activated sludge (Siziriciyildiz, 2012). Aeration and clarification tanks are included in a conventional activated sludge process. For restaurant wastewater, the wastewater flows continuously into the aeration tank, at which point air is injected in order to mix the activated sludge with wastewater and to supply the oxygen needed for the organisms to break down the organic compounds to carbon dioxide, water, ammonium and new cell biomass (Siziriciyildiz, 2012).

The mixture of activated sludge and wastewater in the aeration tank contains a variability of heterotrophic microorganisms such as bacteria, fungi, protozoa and larger microorganisms. The mixed liquor flows from the aeration tank to the final clarifier where the activated sludge is settled out. The activated sludge is separated from the wastewater and most of the settled sludge (known as return sludge) is returned to the aeration tank to maintain a high population of microbes. The principle in activated sludge treatment plants is that a mass of activated sludge is kept moving in the water by stirring or aeration (Mogens Henze, 2013). The disadvantages of this treatment is when more activated sludge than required is produced in the process, some of the return sludge is diverted or wasted to sludge systems. In addition, the activated sludge process has some disadvantages like continuous need for requiring continuous air supply, high operational and investment costs, sensitivity against shock toxic loadings, longer treatment time, and ultimate sensitivity of microorganisms against pH and temperature (Ozyonar & Karagozoglu, 2011).

2.3 History of Electrocoagulation

Electrocoagulation has been used since 1889 for the treatment of sewage and the first plant was built in London. Though some assuring results, the success of this technology has been limited. Despite, there has been renewed scientific, economic and environmental interest in this technology in recent years due to demand of alternative water treatment technologies (Veps, 2010). Electrocoagulation is another method to chemical coagulation in the treatment of wastewater. Electrocoagulation mechanism generally involves iron or aluminium anodes that undergo electrolytic disintegration. Iron and aluminium ions are imported into the processed wastewater where they act as electro-coagulant (Marta, 2012). The electrocoagulation mechanism can be used for the treatment of drinking water and wastewater. Electrocoagulation cell is expressed by coagulant species in situ by electrolytic oxidation of sacrificial anode materials generated by the electric current applied through the electrodes. The metal ions produced by electrochemical dissolution of a consumable anode immediately undergo hydrolysis in water, forming various coagulant species including hydroxide precipitate and other ions metal species. Aluminium and iron materials are the most commonly used as electrode materials because of their various advantages, availability for example abundance on the earth and low price, their non-toxicity, as iron and aluminium hydroxides formed by precipitation are relatively non-toxic, and their high valence that leads to an efficient removal of pollutant. Also, at the same time, cathodic reaction allows for pollutant removal either by deposition on the cathode electrode. The anode and the cathode are usually made of the same metal, despite electro-dissolution should occur only at the anode. Electrocoagulation cell can be conducted as a batch or continuous process (Marta, 2012).

Electrocoagulation cell is an old process same as electricity. The use of electrocoagulation cell in drinking water treatment plants was recorded in the 19th century in England and wastewater treatment plants performed in the USA at the beginning of the 20th century. At the end of the 30s, the electrocoagulation process had been mainly replaced by chemical coagulation and biological treatment for the reduction of colloidal and soluble organic pollutions in wastewater, respectively. Because of the higher operating cost of electrocoagulation, the situation has drastically changed and the advantages of electrocoagulation cell have been reviewed since the 90s (Marta, 2012). The advantages of electrocoagulation cell have further may studies on the use of this technology from treatment of particular industrial wastewater such as palm oil mill effluent, laundry, dairy, biodiesel, paper, oil, electroplating, and textile dyes. There also some commercial use of electrocoagulation cell technology for sewage treatment, leachate and drinking water industry.

2.4 Definition of Electrocoagulation

Electrocoagulation is a technology that removes pollutants such as BOD, COD, TSS and other from water or wastewater. There are physical, biological and chemical treatments for wastewater. Electrocoagulation is considered as one of the main technology of electrochemical reactor for water and wastewater treatment (Rincon, 2011). Electrocoagulation is a process that introduces an electric current into the medium for a period of time and transfer the stream to a clarifier system. It involves destabilizing suspended, emulsified or dissolving contaminants. This process forms three layers which are floating sludge, clean water and sediment layer (Andrade, 2009).

2.5 Principles of electrocoagulation

Electrocoagulation uses electrochemical cell to treat wastewater. Basically, electrochemical is setup with two electrodes which are anode and cathode that is immersed in the electrolyte (wastewater sample) and connected together with electric current either is direct current (DC) power supply or alternating (AC) power supply. Example of electrocoagulation cell is shown in Figure 2.1.

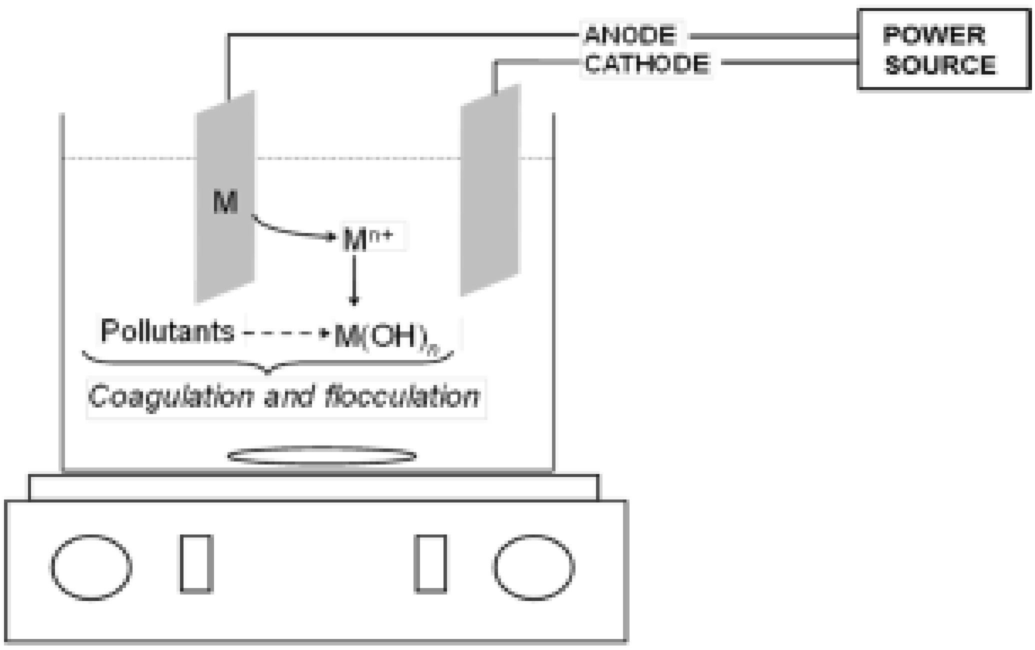

Figure 2. 1 Setup of electrocoagulation cell

Source: Dura (2013)

Electrocoagulation involves three successive stages as below and there is generation of coagulant *in-situ* by passing current through electrode. (Mollah et al., 2004)

1. Electrolytic oxidation of sacrificial electrode to form coagulants
2. Destabilization of contaminants, particulate suspension, and breaking of emulsions
3. Aggregation of the destabilized phases to form flocs

During the chemical process, oxidation and reduction reaction occurs. Oxidation is donation of electron by a molecule, atom or ion whereas reduction is the opposite reaction of oxidation. Oxidation takes place at anode, while reduction takes place at cathode. Anode is known as sacrificial electrode because it releases active coagulant cations via corrosion. Simultaneously, hydrogen gas is produced at cathode. Example of oxidation and reduction is shown below (Matteson et al. 1995; Vik et al, 1984).

At anode, oxidation of metal is occurred and produces cations:

$M_{(S)} \rightarrow M^{Z+}{}_{(aq)} + Ze^-$ Eq 2.1

From the equation, Z is the number of electrons donates in anodic solution process per mole of metal.

At cathode, reduction of water is occurred and produces hydrogen gas and hydroxyl anoin:

$2H_2O_{(l)} + 2e^- \rightarrow H_{2(g)} + 2OH^-{}_{(aq)}$ Eq 2.2

The power source provides current flow in electrocoagulation cell. The driving force from power source gives rise to electron flow and subsequently maintains the current flow. The charged ions are freely move in the electrolyte thus create current flow. High conductivity in electrolyte avoids the high energy consumption and high electrical resistance of the electrolyte.

2.6 Mechanisms Occur at Electrode

The electrodes used for electrocoagulation are aluminium and iron. When there is current transfer across the electrodes, oxidation is occurred at anode while reduction is occurred at cathode. Figure 2.2 shows the process occurs in electrocoagulation. For instance, iron is used for anode, $Fe(OH)_2$ is formed from Fe^{2+}. There are two mechanisms of production of $Fe(OH)_n$ (Mollah et al, 2004). From the equations below, Fe^{2+} is produced from oxidation of iron at anode. Then the product immediately undergoes spontaneous reaction to produce hydroxides and/or polyhydroxides, $Fe(OH)_2$ or Fe $(OH)_3$.

Mechanism 1:

$Fe_{(s)} \rightarrow Fe^{2+}{}_{(aq)} + 2e^-$ Eq 2.3

$Fe^{2+}{}_{(aq)} + 2OH-_{(aq)} \rightarrow Fe(OH)_{2(s)}$ Eq 2.4

Mechanism 2:

$4Fe_{(s)} \rightarrow 4Fe^{2+}{}_{(aq)} + 8e^-$ Eq 2.5

$4Fe^{2+}{}_{(aq)} + 10H_2O_{(l)} + O_{2(g)} \rightarrow Fe(OH)_{3(s)} + 8H^+{}_{(aq)}$ Eq 2.6

Another example of using aluminium as anode during electrocoagulation process is in Eq 2.7 and 2.8. In this case Al $(OH)_3$ is formed from Al^{3+} that undergoes oxidation at anode.

$Al_{(s)} \rightarrow Al^{3+}{}_{(aq)} + 3e^-$ Eq 2.7

$Al^{3+}{}_{(aq)} + 3OH^-{}_{(aq)} \rightarrow Al\ (OH)_{3(s)}$ Eq 2.8

Reduction takes place at cathode. Production of hydrogen gas occurs and cause to changing of pH of solution.

$2H_2O_{(l)} + 2e^- \rightarrow H_{2(g)} + 2OH^-{}_{(aq)}$ Eq 2.9

$2H^+{}_{(aq)} + 2e^- \rightarrow H_{2(g)}$ Eq 2.10

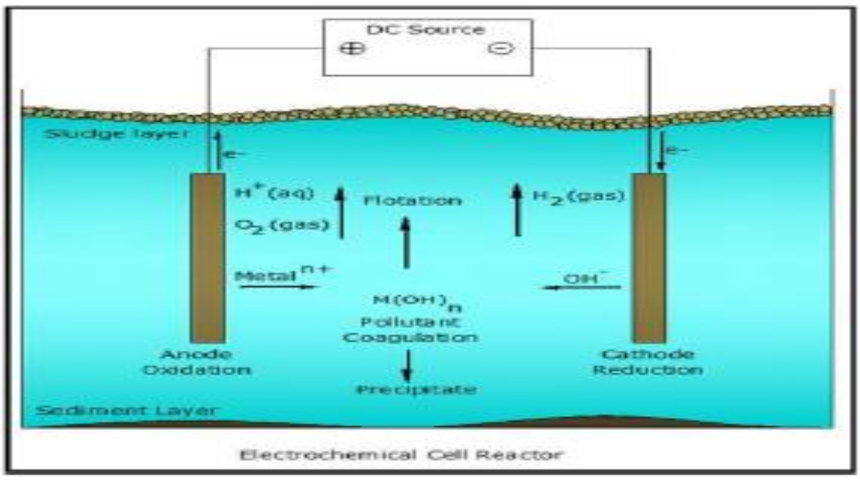

Figure 2. 2 Electrochemical reactor

Sources: Mollah et al (2004)

2.7 Advantages of electrocoagulation

According to Rajeshwar and Ibanez (1994), there are several advantages of electrocoagulation as compared to traditional technologies.

1. Durability of electrodes is good as it does not need much replacement and maintenance.
2. There is no requirement of chemical mixing.
3. Lower amount of chemical is required. For instance, in conventional lime-neutralization processes, water hardness is increased.
4. The smallest charged colloids can move easier than larger counterparts. As a result, they can be treated and avoid usage of mechanical agitation which will destroy precipitates formed.
5. Sludge produced from electrochemical treatment is more hydrophobic and has higher dry solids which cause to denser residues. Moreover, it also shortens the decantation times. For instance, conventional addition of ferric chloride followed by sodium hydroxide or lime produces up to 30L of sludge for every litre of removed oil.
6. Cheaper than conventional technologies because operating cost is lower.
7. Nearly 90% of current efficiency is achieved in well-designed system.
8. Effective removal of organic matter which facilitates subsequent biological treatment.

Meanwhile, according to Siringi et al.(2012), the advantages of electrocoagulation are almost same as stated above except for the below:

1. Wastewater treated by electrocoagulation gives palatable, clear, colourless and odourless water.
2. Simple equipment is required and easy to operate with adequate operational latitude to handle most problems on operating.
3. Electrocoagulation is convenient technique because solar panel can be attached to the unit if there is no electricity in rural areas.

2.8 Other Application of Electrocoagulation

Nowadays, the electrocoagulation process was one of the proposing method that be able to treat and removing the contaminants in wastewater. There was researched that show the capabilities of the electrocoagulation in treatment of the wastewater. For example, the electrocoagulation technology is used in the treatment of paper mill effluent. Katal & Pahlavanzadeh investigated the effective performance of electrocoagulation process in the treatment of paper mill wastewater using the different combination of aluminium and iron electrodes. In this study, the removal efficiency of the COD, removing colour and phenol was investigated from paper mill wastewater. The influence of factors such as the type of electrode materials and electrolysis time conducted on the removal of colour, phenol, and COD was determined (Katal & Pahlavanzadeh, 2011). The combination used of Al-Al electrode has only effective in the colour removal and the Fe-Fe electrode is effective in the COD and Phenol removal (Katal & Pahlavanzadeh, 2011). The weakness of this study is the electrode material only effective on the certain pollutant. It is not effective to treat the colour, COD, and phenol at the same time. This study also not consider the other electrode factor such as arrangement and orientation of the electrode. Using this other electrode factor, may affect and increase the efficiency of the electrocoagulation process.

Dergisi & Journal conducted an experimental investigation of paper mill effluents treatment using the electrocoagulation method. This study covers the removal of COD, BOD, and other pollutants. The experimental considered the electrolyse time and types of electrodes (Dergisi & Journal, 2004). The electrode used was aluminium and iron. The removal efficiency of COD and BOD of this observation required longer electrolyse times (Dergisi & Journal, 2004). Thus, this electrocoagulation should be able to remove the COD and BOD in short amount times. The consideration of electrode factor may affect removal efficiency and can treat the contaminant in short amount of time. Hubbe et al. tested the effect of batch electrocoagulation using two parallel iron or aluminium plates for 90 min. The result from this study shows that the removal ranged from chemical oxygen demand is between 32% to 68% and dissolved organic carbon is between 24% to 46% (Hubbe et al., 2016). The removal of the COD is low but the raw paper mill effluent had a high concentration of COD and suspended solids contents (Hubbe et al., 2016). Moreover, the aluminium electrode only being able to remove the COD in ranged 47% and 68% and the iron electrode in ranged 32% and 41% (Hubbe et al., 2016). Furthermore, the suspended solids content is not considered as the contaminant that should be removed from the wastewater. The electrocoagulation does not consider the electrode factor as the effect variables in the treatment of the paper mill wastewater and also the period of time used for the treatment is 1 hour and a half that makes the treatment need longer time to the treat the paper mill wastewater.

The others of the application of electrocoagulation process was in the textile dyes wastewater treatment. The textile industry wastewater effluent has a high concentration of COD and colour content. The electrocoagulation technology is the alternative way to treat the textile wastewater. Akanksha, Roopashree, & Lokesh studied the electrocoagulation process using iron, aluminium and stainless steel electrode as the factor to investigate the reduction of the COD and colour content concentration. This study considered the used of the iron electrode was found to be more efficient than other electrodes in removal of the COD and colour content (Akanksha et al., 2013). The results show that the reducing amount of the concentration COD and colour is high but the treatment need 80 min to treat the wastewater (Akanksha et al., 2013). For other electrode, it need high voltage in order to achieve removal efficiency same as the iron electrode. Furthermore, this study not consider the other electrode factor such as arrangement and orientation. The problem may be solved by considering the arrangement and orientation of the electrode. Thus, the removal efficiency can be increase and the time consuming to treat the textile wastewater will be decrease.

Another study has been devoted to find the electrocoagulation efficiency of treatment of textile dyeing wastewater (Kobya, et al., 2014). The textile dyeing contained with high concentration of COD, total organic carbon (TOC), colour, and turbidity was treated by electrocoagulation process (Kobya et al., 2014). The electrocoagulation were used the aluminium and iron plate electrodes with independent variables such as current density, an initial pH and an operating time (Kobya et al., 2014). The result from this studied showed that, for iron electrode were 77% for TOC, 82 % for COD, and 94 % for turbidity and for aluminium electrode were 68% for TOC, 69% for COD, and 99% for turbidity in removal percentage in one an half hour (Kobya et al., 2014). The removal efficiency of turbidity is quite low than other contaminant. The treatment could be better by considering the electrode factor because the reaction of electrocoagulation will be different when it is oriented and arranged with different types.

Application of the electrocoagulation is also being studied in the treatment of laundry wastewater. The department of safety health and environmental engineering in Chung Hwa University of Medical Technology, Tainan Country, Hsien 717, Taiwan has conducted study in the treatment of simulated laundry wastewater using electrocoagulation process in the removal efficiency of COD (Wang et al., 2009). This study stated that the used of the electrocoagulation cell can increase the removal efficiency of COD in the laundry wastewater (Wang et al., 2009). Another study was conducted in the treatment of laundry wastewater using one of the electrode factor of new bipolar electrocoagulation process (Ge et al., 2004). This aim of this experiment was to developed the treatment process of laundry wastewater that can removed the turbidity, COD, phosphate and methylene blue active substance (MBAS) contains (Ge et al., 2004). The result showed that, the removal of COD was greater than 70% and the removal efficiencies of MBAS, turbidity and phosphate be able to reached above 90% (Ge et al., 2004).

The electrocoagulation was an appropriate method for use in removing nitrate, phosphate, COD, turbidity, and TSS from wastewater stated by Ge et al. This study was to evaluate the efficiency of the electrocoagulation process in removing turbidity, total suspended solid, chemical oxygen demand, nitrate, and phosphate from wastewater facility in Karaj, Iran (Ge et al., 2004). The experimental was conducted at a pilot scale and in a batch system with a 4 litre tank made from safety glass with 4 plate electrodes made from aluminium was unipolar connected to a direct current power supply with a parallel arrangement (Ge et al., 2004). The reaction time of the treatment was 30 minutes and achieved high removal efficiency. The Department Of Environmental Health Engineering in Mazandaran University of Medical Sciences, Sari, Iran has studied the treatment of hospital laundry wastewater pre-treatment by electrocoagulation process (Zazouli et al., 2016). The electrocoagulation process be able to removed 89.1, 77.8, 81, and 78% of COD, colour, phosphate and surfactant, respectively (Zazouli et al., 2016). From this study, the electrocoagulation process using iron electrode was a very efficient and reliable treatment process for the pre-treatment of hospital laundry wastewater. Hence, the electrocoagulation process should be used for hospital laundry wastewater at full scale as a suitable technology (Zazouli et al., 2016).

The electrocoagulation process has many potentials in treatment of industrial and commercial wastewater. Hence, electrocoagulation process also has the capability in the removal of oil in wastewater. There were several studies about the electrocoagulation cell as the oil removal and give the more efficient way to extract the oil contaminant in wastewater. The faculty of Engineering and Applied Science in Regina University, Regina, Canada had conducted the review of emerging electrochemical technologies used for treating oil containing wastewater (An et al., 2017). There were several source of oil containing wastewater such as from petroleum refinery (El-naas et al, 2013), metal processing and finishing (Odongo & Mcfarland, 2009), food processing (Barrera-dı et al.,2006), slaughterhouse (Kobya et al., 2006), tannery (Jing-wei et al., 2007),and restaurant wastewater (Bay, 2000). The development of electrode materials, application of different electrode arrangement, and optimal design for cells can increase the efficiency of the oil removal and also the electrocoagulation process (An et al., 2017). This process could be applied to mitigate the impact of environment disaster with the massive oil spilled and have potential for treating the surface water and groundwater that contaminated by oil (An et al., 2017).

In this study, the application of electrocoagulation on the oil and grease removal can be applied to restaurant wastewater. The past researched, studied the effect of operating parameter of electrocoagulation process in the treatment of restaurant wastewater. The research about considering the effects of material, arrangement, and orientation of the electrode factor of electrocoagulation process not yet be study in any articles.

Landfill leachate contains high concentration of BOD, COD and heavy metal. A study is done by Tezcan Un et al. about the treatment of landfill leachate using continuous electrocoagulation. Iron electrodes (anode and cathode) are used to conduct electrocoagulation in 60 minutes time. It is recorded that COD removal efficiency is 58% at pH of 5 which mean from a concentration of 6400mg/L drops to 2700mg/L. Nonetheless, aluminium electrodes are used to compared with iron electrode in the study from Contreras et al. The experiment starts by applying 3A of current, pH of 7.42 and inter-electrode distance of 20mm in 30 minutes. In the study, iron has higher COD removal (45.7%) as compared with aluminium (32.4%). From the studies, iron electrode is more suitable to be used in treatment of landfill leachate. U & Oduncu studied on removal of COD from landfill leachate using aluminium electrode. The initial condition of the leachate was at pH of 9 and concentration of 4100 mg/L. The experiment setup was using six aluminium plates and connected using a monopolar configuration which three aluminium plate operated as anode. The highest efficiency of COD removal was 48% at pH5.

Nasrullah et al. studied the electrocoagulation using several types of electrode factor in the treatment of Palm Oil Mill Effluent (POME). The removal efficiency of the electrocoagulation cell was noted in removal of COD, BOD and TSS. The electrode factor was contributed in the removal efficiency have being studied in order to achieved highest removal efficiency. The studies have shown the highest removal efficiency of 74%, 70% and 66% for COD, BOD and TSS respectively from the electrode factor using the steel wool.

2.9 Effect of Electrode Materials

Choice of electrode is very important as it is heart of present treatment facility. The most common electrode materials for electrocoagulation are aluminium and iron. Moreover, they are proven effective, readily available and cheap (Chen et al., 2000).

With direct current applied Al^{3+} and Fe^{2+} ions are produced due to the dissolving of anodes. Presence Fe^{2+} causes the treated water become green colour and then change to yellow and turbid. This is because Fe^{2+} is oxidised to Fe^{3+} in acidic or neutral conditions. The changing of yellow colour is because of the production of $Fe(OH)_3$ from reaction of Fe^{3+} and OH^- (Barrera-Díaz, et al., 2003).

The selection of electrode material can affect the induction of oxidation of electrodes. Constant current is applied to generate metal ions which are compulsory in forming coagulation and flocculation of pollutant. Electrochemical properties of electrode material and the resistance to corrosion or dissolution can affect the power consumption (Dura, 2013).

Other than that, electrode material determines the concentration and the types of coagulant delivered to the solution. Every material has its rate of dissolution that can affect the energy consumption (Dura, 2013). In this study, aluminium and iron are chosen as electrode material. Therefore, the behaviour of the metal is discussed. Due to the exposure to environment, metallic materials change and cause corrosion. There many types of corrosion which depends on the environment, ranging from uniform corrosion to localised corrosion. The development of oxide-containing film is due to the reactions with the environment (Kruger el al. 2006). These oxide-containing films are protective and provide more corrosion resistant metal or alloy surfaces. In addition, they decrease the corrosion of metal or alloy (Uhlig, 2000).

During electrocoagulation, there is an aqueous film in air that covers the metal surface and cause to corrosion. Then, two reactions occur which are dissolution or oxidation of iron and reduction of dissolved oxygen. As a result, the dissolution of iron occurs followed by the formation of iron hydroxide (Evan et al., 1965).

Amount of metal dissolution of electrode material can be calculated by using Faraday's Law. The formula is driven as Eq 2.11 below. A study is done by Mouedhen et al. on the behaviour of aluminium electrode in electrocoagulation process has reported that aluminium has more than 100% and reach 200% of faradic yield. Meanwhile, a study that is done by Mansouri et al. the faradic yield can reach to 80%.

$$m = \frac{ItM}{zF} \qquad \text{Eq 2. 11}$$

where:

m = the mass of anode dissolved (g),

I = the current (A),

t = the time of operation (s),

M = Molar mass of the electrode concerned (g/mol^{-1}),

z = the number of electrons in oxidation/reduction reaction

F = Faraday constant (96485.3 C mol^{-1})

Conventional electrode materials perform lower current efficiency because of the water electrolysis side reactions. Therefore, effluent and water treatment by electrochemistry is comparatively low (Comninellis 1994; Simonsson 1997). However, the use of sacrificial electrodes of metals which result in numerous charged ions and their corresponding salts in the electrolytic systems can give rise to coagulation and flocculation of soluble and dissoluble water impurities. This aids in the elimination of contaminants from wastewater.

Chopra & Sharma (2013) studied the removal of turbidity, COD and BOD from secondarily treated sewage water. The studied is carried out by using aluminium and iron by interchanging the cathode and anode position. This study revealed that the effluent can be effectively treated with the aluminium (Al) and iron (Fe) electrode combinations (Al–Fe and Fe–Al). Al–Fe electrode system has higher efficiency of COD and BOD removal which are 81.51 %, 74.36 % and 70.86 % respectively. Meanwhile, Fe–Al electrode combination recorded 71.11%, 64.95% and 61.87 % respectively. Aluminium is superior as a sacrificial electrode over that of iron.

Katal & Pahlavanzadeh studied influence of different combinations of aluminum and iron electrode on treatment of paper mill wastewater. It was found that Fe–Fe and Fe–Al electrode pairs have higher removal efficiency than with Al–Al and Al–Fe electrode pairs in COD removal. Efficiency of Al and Fe is yet to be investigate due to different result from Chopra & Sharma and Katal & Pahlavanzadeh.

Akanksha, Roopashree, & Lokesh studied the electrode material (aluminium, iron and stainless steel) for trestment of textile industry wastewater. The experiment was setup by using six monopolar electrodes, three anodes and three cathodes of same dimension of 5cm x 5cm x 1mm. Iron electrode achieved 90.12% removal of COD at 8V in 80 minutes. Meanwhile, aluminium and stainless steel recorded 92.97% and 87.23% respectively at 14V in 80 minutes. The descending effectiveness of eletrode material in removing COD from textile industry wastewater is aluminium, iron and stainless steel.

The smilar result is got in the research done by Nasution et al. on Palm Oil Mill Effluent (POME) treatment. The experiment is carried out by using aluminium and iron electrodes. From result, the COD and turbidity was reduced around 57.66% and 62.5% respectively by using aluminium electrode. However, for iron electrode, it only can reduce to 35.3% and 43.1% of COD and turbidity respectively. Aluminium performs better than iron in term of COD and turbidity removal. Nonetheless, according study done by Nasrullah et al. (2018) iron has better removal of COD, BOD and SS from POME as compared with aluminium in 120 minutes. Iron electrode able to remove 72% of COD, 67% of BOD and 63% of SS while aluminium electrode can remove 65% of COD, 62% of BOD and 60% of SS. There is still uncertainty to be investigated about the effectiveness of electrocoagulation by using aluminium and iron electrode.

Chen el at. studied separation of pollutant from restaurant wastewater by using aluminium and iron electrode. The result recorded was both aluminium and iron electrode are equally effectiveness at which over 90% of COD, BOD and SS are removed in one and half hour. Moreover, there is 100% removal of oil and grease with an initial concentration of 1500mg/L. The problem of using iron electrode is because of corrosion occurs at open circuit. Therefore, it is preferable to use aluminium electrode to longer the lifetime of electrode as compared with iron.

Bay studied the electrocoagulation of restaurant wastewater. The experiment is setup by using six electrodes which are three aluminium electrodes are connected with three stainless steel electrodes that are arranged in parallel. The COD, COD, SS, oil and grease are examined by the standard method. The initial concentration of COD is 1370mg/L, oil and grease is 325mg/L while SS is 225mg/L. The result reported was 61.1%, 98.5%, 96.4% for removal of COD, OG and SS respectively. There is improvement for COD since it only recorded 61.1% of removal.

Murthy el at. studied the separation of pollutants from restaurant wastewater by electrocoagulation. The wastewater sample was collected from kitchen drainage that may include bakery items and all food preparation. Aluminium has better result of removing COD as compared with iron in 30 minutes time. The initial concentration of 1400mg/L has decreased to 700mg/L. Besides, aluminium has clearer and stable effluent as compared with iron.

2.10 Summary of literature review

In the nutshell, the application of EC to treat wastewater still has some limitation. Therefore, operating parameters selected should use in wider range to increase the efficiency of EC since the value of range can affect the result and effectiveness of EC. In this study, the operating parameter selected is electrode material. The performance of electrode material will be observed and adjusted to get the best result.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The experimental setup used in this study is shown at figure 5. The sample used is restaurant wastewater at Malay cuisine restaurant located at Teluk Cempedak, Pahang. Then, the concentration of BOD, COD and TSS before and after treatment was measured using standard method. The electrode materials used are aluminium (Al-Al), iron (Fe-Fe) and composite electrode (Al-Fe, Fe-Al).

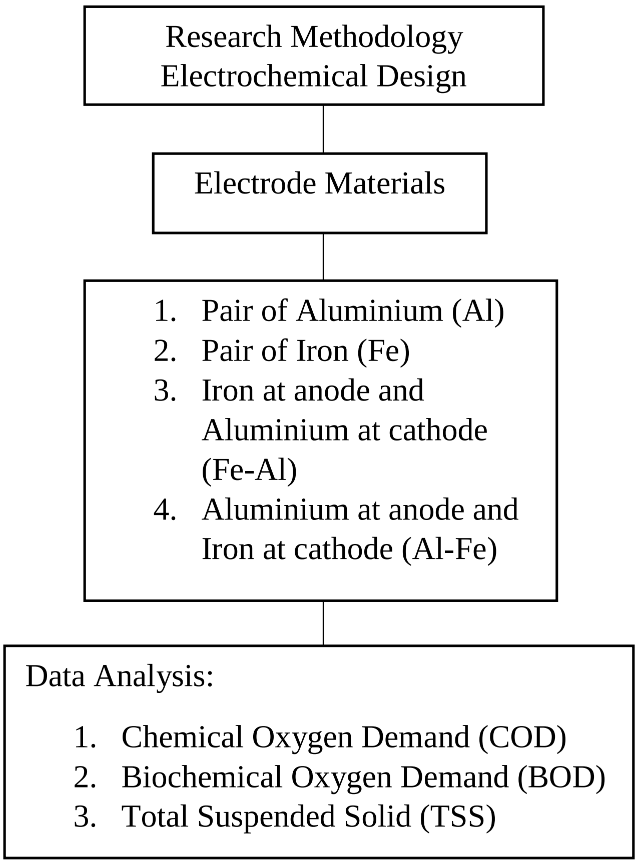

Figure 3.1 Flow Chart of research methodology

3.2 Experimental Set Up

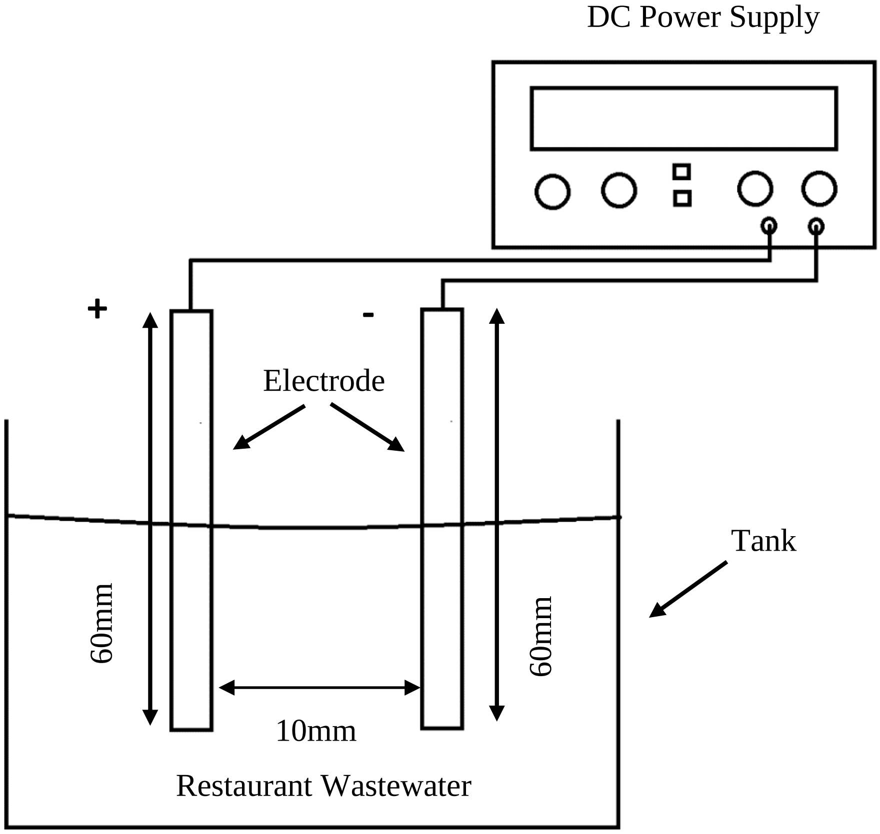

Figure 3.2 Schematic diagram of the experimental setup.

The experimental setup is shown above consists of a 1000 mL beaker as a reactor to hold a sample of 1000 mL, a power source, electrodes and restaurant wastewater sample. The electrode materials are determined to observe the removal of the BOD, COD and TSS. The dimension of aluminium and iron electrode is 30 mm x 60 mm each. The thickness of the electrode is 3 mm each. The electrodes are mechanically cut according to the size and all the dirt and corrosion on the plates are remove using hydrochloric acid (HCl) with concentration of 35% and then with hexamethylenetetramine 3%. The area of electrode immerse into the solution sample is 30 mm x 50 mm whereas the remaining is avoided from exposure by applying the lacquer on top of every electrode. All the electrodes are immersed into the hydrochloric acid (HCl) with concentration of 35% and then with hexamethylenetetramine 3% for about 5 minutes and wash with tab water before start the experiment. The current intensity is controlled by a DC Power Supply which is set at 3 A. The experiment is carried out for 120 minutes with 30 minutes interval. At every 30 minutes, the sample is extracted out using micropipette to test the concentration of BOD, COD and TSS to determine the efficiency of removal. The method used to test BOD, COD and TSS are dilution method: Method 8043, digestion method: Method 8000 and Method 2540D respectively.

3.2.1 Preparation and Characteristics

Restaurant wastewater is water that has been used for cleaning meats, rice, seafood, vegetables, washing dishes and cooking utensils**.** In the present study, restaurant wastewater containing high concentrations of biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS) was treated by the electrocoagulation process. The wastewater collected from the Malay food premise at Teluk Cempedak, Pahang was used for all experiments regarding the selection of different electrode materials and the effects of operating parameters on treatment efficiency.

The samples were taken to remove for BOD, COD and TSS. 4 L container was used to transport 4 L samples to the laboratories for analysis and the sample was stored in a chiller at 4 ^{o}C in Chemistry Laboratory UMP to make sure the sample not affect and expose to the light. The sample was also preserved and handled before analysis according to the prescribed standard procedures for the analytical methods used. In addition, there was no chemical added in the sample.

3.3 Experimental Technique for Electrochemical Design

3.3.1 Procedure to Determine the Effect of Electrode Material

The experiment was carried out to study the effect of electrode material on BOD, COD, and TSS removal from restaurant wastewater. The electrode materials used were Al and Fe with dimension of 60 mm x 30 mm, 3 mm thickness and 10 mm distance between two electrodes. Electrode material at anode and cathode was changed according to experimental purpose which is shown in Figure 6 to Figure 9 (Al-Al, Fe-Fe, Al-Fe and Fe-Al). The current intensity was set at 3 A and 120 minutes for each experiment. At the end of each experiment, the electrode was washed with water, dried and finally weighed to calculate the amount of metal dissolution.

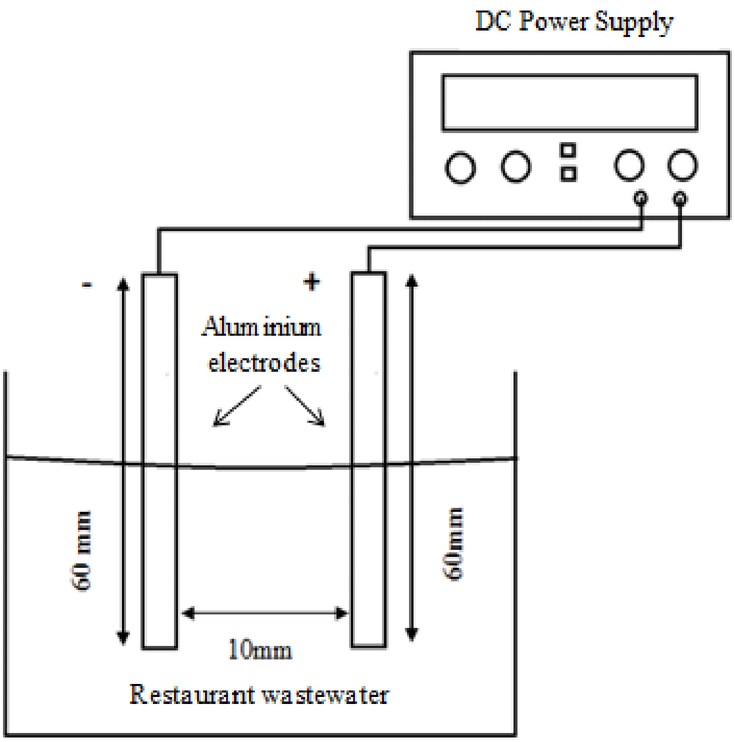

Figure 3.3 Schematic diagram of Al-Al electrodes experimental setup

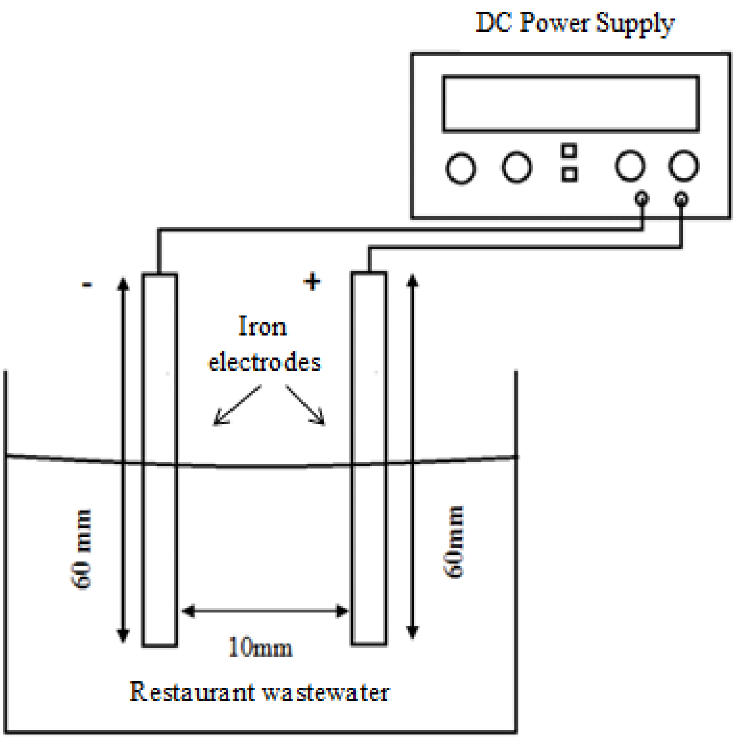

Figure 3.4 Schematic diagram of Fe-Fe electrodes experimental setup

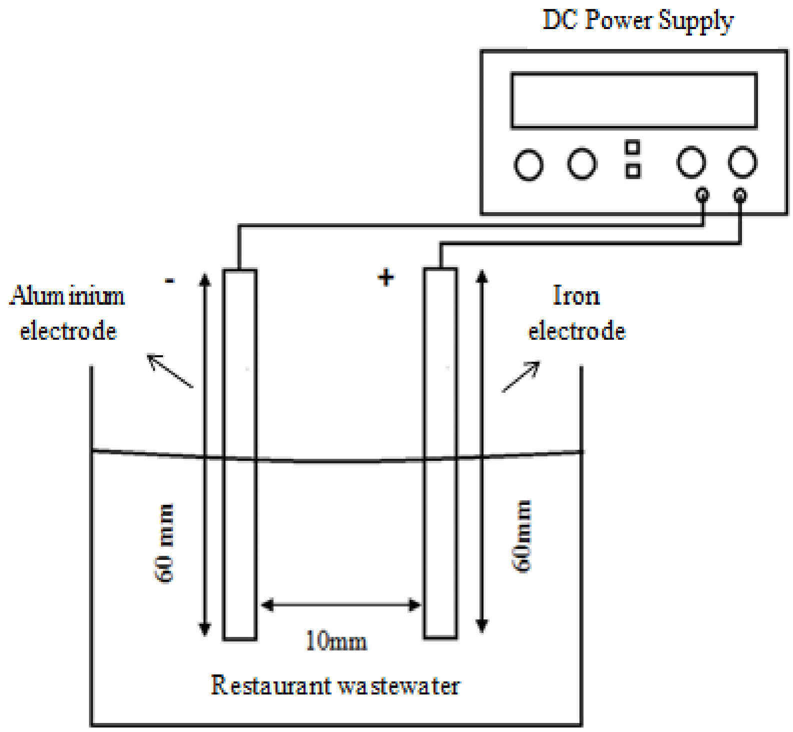

Figure 3.5 Schematic diagram of Al-Fe electrodes experimental setup

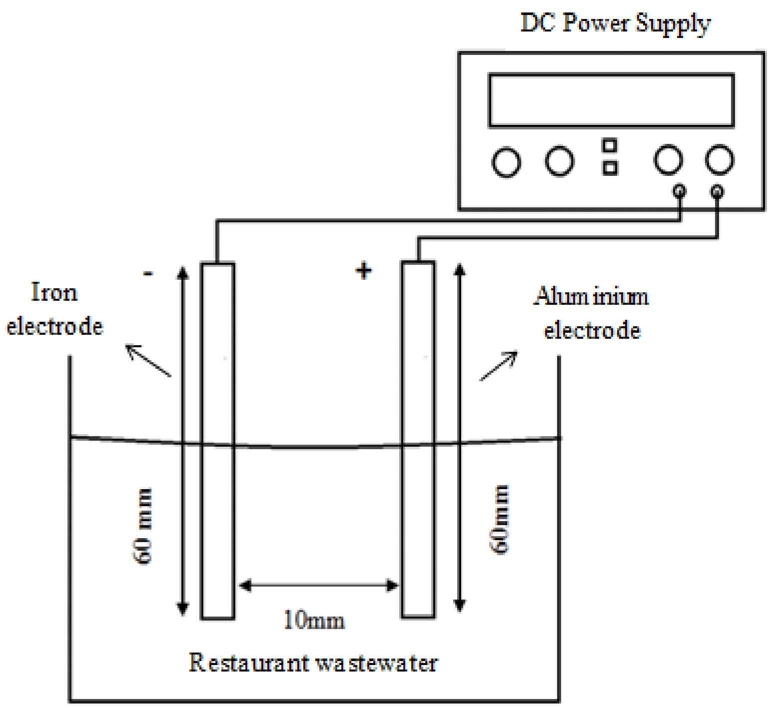

Figure 3.6 Schematic diagram of Fe-Al electrodes experimental setup

3.4 Test Parameters Analysis

3.4.1 Biochemical Oxygen Demand

Test procedure HACH, Method 8043

1. Five sample volumes were identified to use for this test.
2. The sample was stir gently.
3. A pipet was used to add the sample volumes to five 300-mL BOD bottles.
4. Each bottles were filled with prepared dilution water.
5. A stopper was inserted in each bottle to prevent trapped air bubbles. The stopper was pushed down and the bottles were inverted several times to mix.
6. The blank was prepared. Another 300-mL BOD bottle was filled with the prepared dilution water.
7. A probe was used to measure the dissolved oxygen concentration in each bottle.
8. A stopper was inserted carefully in each of the prepared sample bottles to prevent trapped air bubbles. Dilution water was added above the stopper of BOD bottles to make a water seal.
9. A cap was added to each bottle to prevent evaporation.
10. the prepared sample bottles were kept in an incubator at 20 °C. Do not move the prepared sample bottles for 5 days.
11. After 5 days, the remaining dissolved oxygen were measured in each of the prepared samples.
12. The BOD value was calculated.

Calculation:

$$BOD_5 \text{ at } 20°C = \frac{D_1 - D_2}{P} \qquad \text{Eq 3.1}$$

Where:

D_1: Dissolve oxygen (DO) of the prepared sample immediately after preparation (mg/L)

D_2: Dissolve oxygen (DO) of the prepared sample after incubation (mg/L)

3.4.2 Chemical Oxygen Demand

Test procedure HACh, Method 8000

1. The DRB200 Reactor was preheated to 150°C.
2. The cap was removed from a vial for selected range. A clean pipet was used to add 2.00 mL of wastewater sample to the vial.
3. The cap was removed cap from a second vial for the selected range. A clean pipet was used to add 2.00 mL of deionized water to the vial.
4. The vials were closed tightly.
5. The vials were hold by cap, over a sink. Then, vials were inverted gently to mx.
6. The vials were put in preheated DRB200 Reactor. The lid was closed.
7. The vials were heated for 2 hours.
8. The vials were cooled in reactor for approximately 20 minutes to 120°C or less.
9. Each vial was inverted several times while it is still warm.
10. The vials were out in a tube rack to cool to room temperature.
11. Program 435 COD HR was started.
12. The blank sample was inserted into cell holder.
13. ZERO was pushed. The display showed 0 or 0.0 mg/L COD.
14. The prepared wastewater sample was inserted into cell holder.
15. READ was pushed to show results.

3.4.3 Total Suspended Solid

Test procedure Standard Method, Method 2540D

1. Glass fiber filter was inserted disk with wrinkled side up into filtration apparatus. Vacuum was applied and wash disk with three successive 20-mL volumes of reagent-grade water. suction to remove all traces of water was continued. washings were discarded.
2. If only total dissolved solids are to be measured, clean dish was heated to 180 ± 2°C for 1 h in an oven. Then, weighed immediately before use.
3. Sample volume was chosen to yield between 2.5 and 200 mg dried residue.

4. Sample was stirred with a magnetic stirrer and a measured volume was pipetted onto a glass-fiber filter with applied vacuum. The sample was washed with three successive 10-mL volumes of reagent-grade water, allowing complete drainage between washings, and suction was continued for about 3 min after filtration is complete. Total filtrate was transferred to a weighed evaporating dish.
5. evaporated sample was dried for at least 1 h in an oven at 180 ± 2°C, cooled in a desiccator to balance temperature, and weighed.

Calculation:

$$\text{Total Suspended Solid (TSS)}=\frac{\text{A-B} \times 1000}{\text{sample volume, mL}} \qquad \text{Eq 3.2}$$

Where:

A = weight of filter + dried residue, mg

B = weight of filter, mg

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

This research was carried out to study the effect of electrode material to treat restaurant wastewater by using electrocoagulation method. The types of electrode materials used were aluminium and iron. Four combinations of iron and aluminium plates was investigated in this study in order to determine the optimum electrode pair which were using aluminium electrodes at both anode and cathode (Al-Al), iron electrodes at both anode and cathode (Fe-Fe), aluminium electrode at anode while iron electrode at cathode (Al-Fe) and iron electrode at anode while aluminium electrode at cathode (Fe-Al). The efficiency of pollutants removal was based on three parameters which were BOD, COD and TSS.

The concentration of BOD, COD and TSS were analysed before treatment and 30 minutes interval during treatment. The calculation of BOD, COD and TSS removal efficiency after 120 minutes of treatment period was carried out by using the following formula:

$$CR\ \% = \frac{C_o - C}{C_o} \times 100 \qquad \text{Eq 4.1}$$

where,

C_o = concentration of BOD, COD and TSS before treatment, mg/L

C = concentration BOD, COD and TSS after treatment, mg/L

4.2 Result tabulation

From the figures above, during the study of electrocoagulation of restaurant wastewater treatment, increase of treatment duration can increase the removal efficiency of BOD, COD and TSS until an optimum removal efficiency was reached. Treatment period from 0 minute until 120 minutes showed the decreasing of BOD, COD and TSS concentration where the concentrations were tested in every 30 minutes interval. Same result was reported by (M. Kobya & Delipinar, 2008) in the treatment of baker yeast wastewater, the concentration of TOC, turbidity and COD were decreased with the increasing of treatment period from 10 minute to 60 minutes.

Al-Fe combination provided the best and most reliable removal of three parameters, BOD, COD and TSS. Observed removal efficiency of BOD, COD and TSS with Al-Fe electrodes was 98%, 91.4% and 86.9% respectively after 120 minutes of treatment. However, Al-Al proved the worst treatment among all electrode combinations. From the observed removal efficiency of BOD, COD and TSS, the result shown was 70.9%, 85.7% and 64.4% respectively. When comparing aluminium and iron electrode, iron showed lower removal efficiency of BOD, COD and TSS. Fe-Al electrodes showed a result of 80.7%, 96.7% and 63.0% of BOD, COD and TSS removal efficiency respectively. While, Fe-Fe electrodes achieved 80.6%, 95.7% and 61.5% efficiency removal of BOD, COD and TSS.

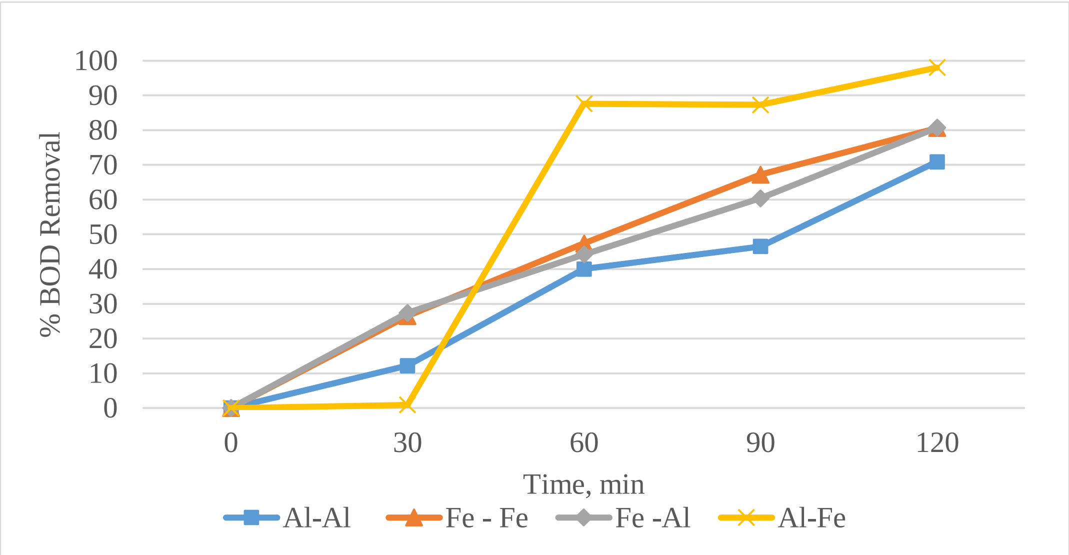

Figure 4.1 BOD removal efficiency against duration of 120 minutes at 3 A and 10 mm inter-electrode distance.

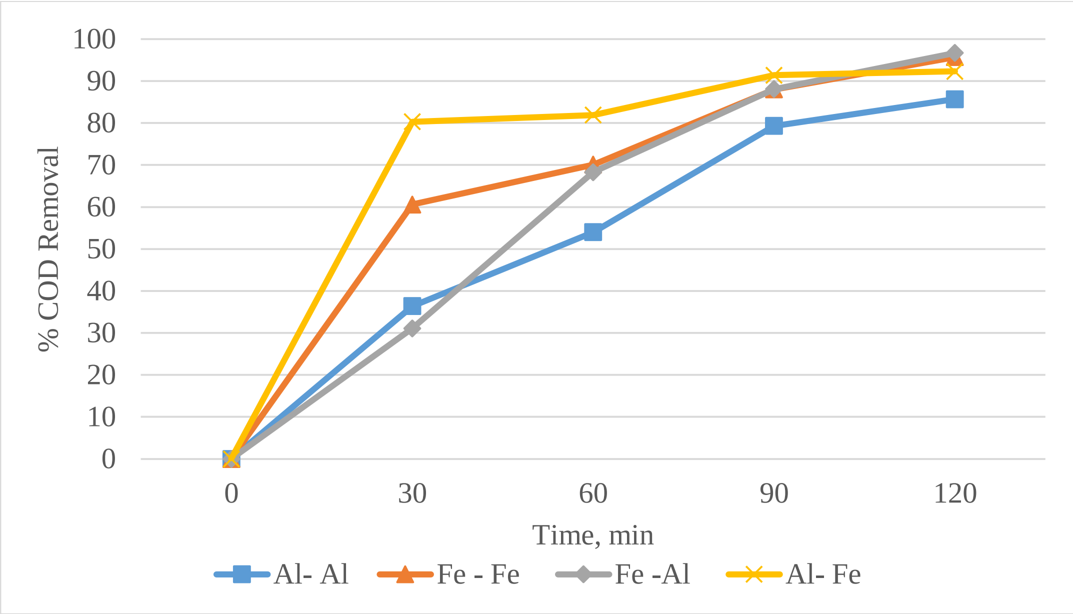

Figure 4.2 COD removal efficiency against duration of 120 minutes at 3 A and 10 mm inter-electrode distance.

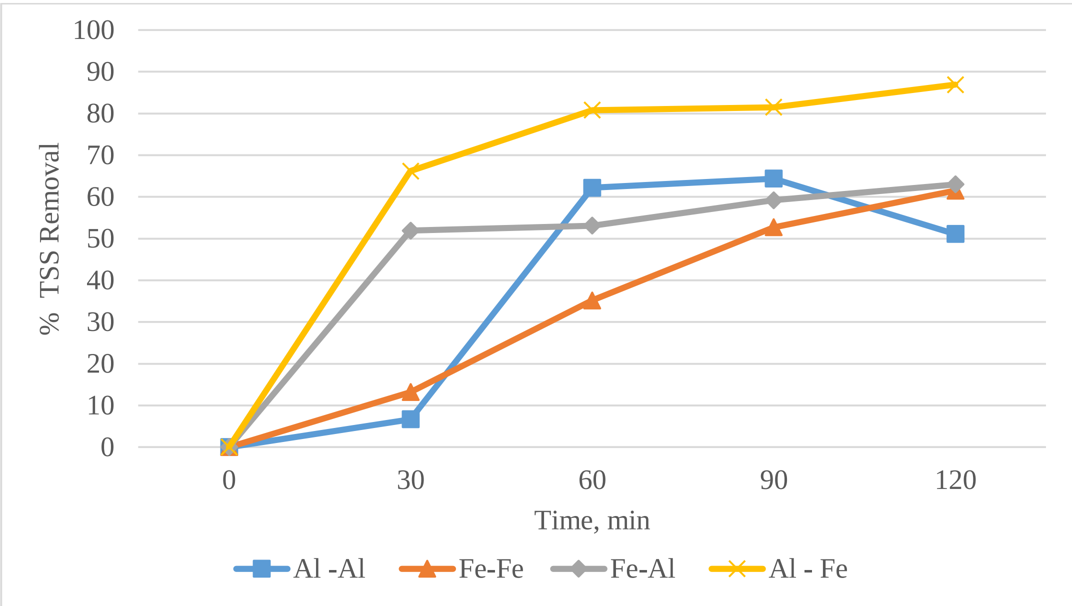

Figure 4.3 TSS removal efficiency against duration of 120 minutes at 3 A and 10 mm inter-electrode distance.

4.3 Effect of electrode materials at anode

Aluminium at anode will undergo oxidation and produce trivalent cation, Al^{3+} which has high coagulation efficiency. Al^{3+} reacted with hydroxyl ion from the cathode to form aluminium hydroxide which help in coagulation. The great performance of aluminium in electrocoagulation in restaurant wastewater treatment probably was attributed to the better coagulating properties of Al^{3+} to those products of Fe. Al^{3+} neutralised the negative charge of colloidial pollutants resulting coagulation and colloid was removed by settling, surface complexation and electrostatic attraction in comparison to Fe^{2+} ions (Chopra & Sharma, 2013).

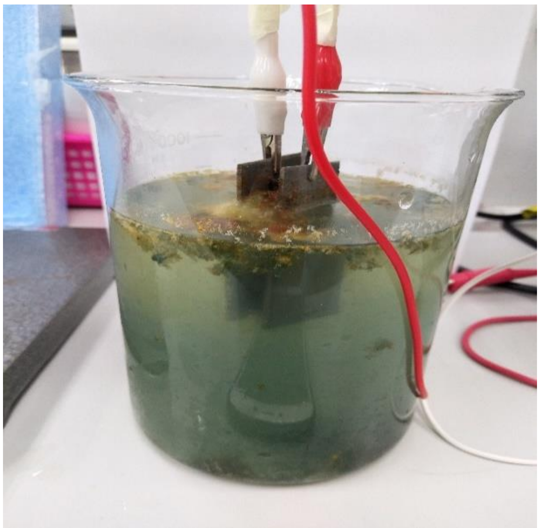

Figure 4.4 Restaurant wastewater change to pale green when using Fe-Fe electrodes at 30 minutes of treatment time.

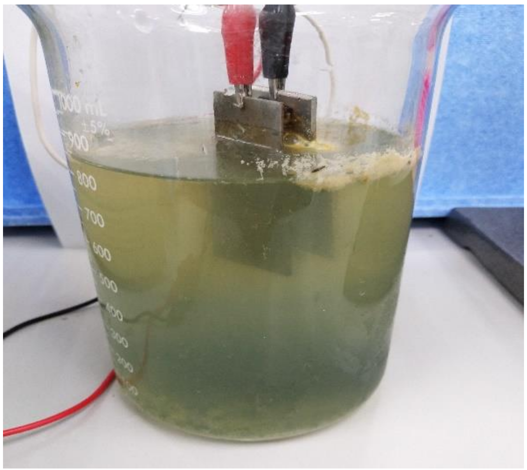

Figure 4.5 Restaurant wastewater change to pale green when using Fe-Al electrodes at 30 minutes of treatment time.

Meanwhile, iron at anode will dissolve into divalent cation, Fe^{2+} and Fe^{3+} to form iron compound depends on the pH of the solution. The mechanism of iron dissolution is not consistent and lack of experimental prove the actual species produced during EC. From the observation in Figure 4.4 and Figure 4.5, the restaurant wastewater changed to pale green which meant Fe^{2+} was generated instead of Fe^{3+}. The process of Fe^{2+} further oxidised to form Fe^{3+} that finally hydrolysed to $Fe(OH)_3$ did not occurred because the pH was unfavourable for Fe^{2+} oxidation. Therefore, Fe^{2+} has lower positive charge as compared with Al^{3+}. Lower positive charge revealed that weaker ion ability to destabilise the colloids. (Moreno C et al., 2009) showed that the green rust formed by iron electrodes and EC accelerated the corrosion of iron by measuring the pH at different locations near iron electrode.

4.4 Effect of electrode materials at anode

On the other hands, the bubbles production at cathode also affect the pollutants removal efficiency. Reduction was took placed at cathode by receiving the electrode released from anode to produce hydrogen gas which is the bubble. From the observation in Figure 4.6 and 4.7, Al produced bigger bubbles as compared with Fe. This is because of the roughness surface of Al. Also, bigger bubble will lessen the flocculation and disintegrate the flocs formed (Lakshmi & Sivashanmugam, 2013). Fe is better in bubbles yield that is small and great in amount. The bubbles helped in removing the suspended solid by flocculation and floated on top of the wastewater.

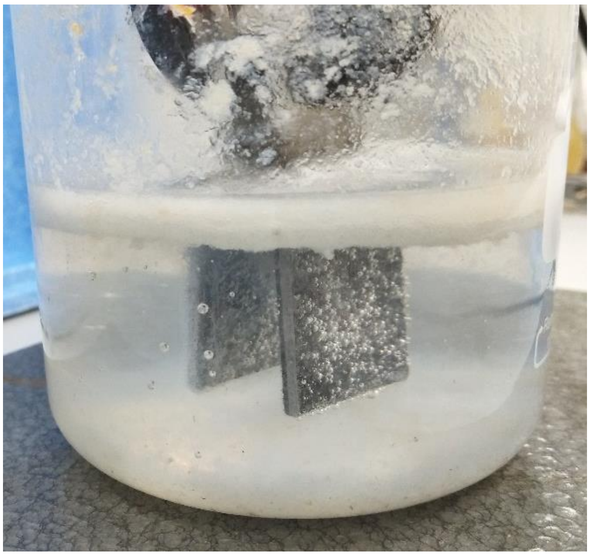

Figure 4.6 Bubbles production at Al cathode by using Al-Al electrodes.

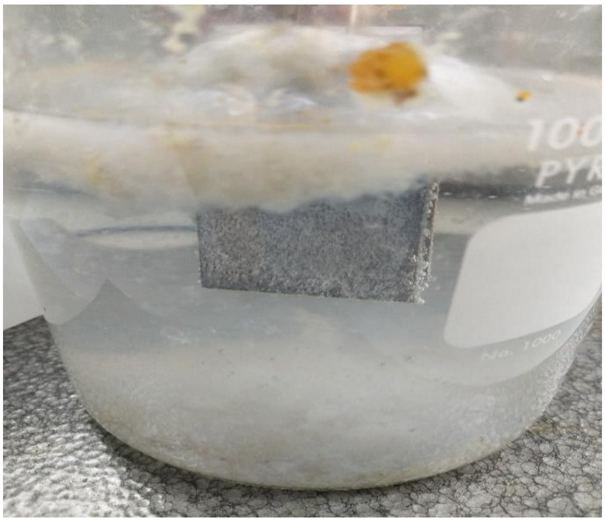

Figure 4.7 Bubbles production at Fe cathode by using Al-Fe electrodes

From observation in Figure 4.8, the suspended solids are float onto the wastewater surface. Hydrogen gas served as good floatation agent when the bubbles produced was increased in density with reduction in size. This encourage the upward flux and thus boost the pollutant removal efficiency (Nasrullah et al., 2018).

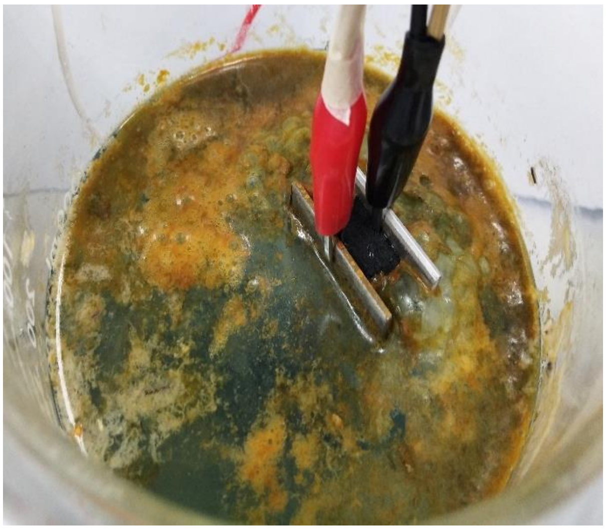

Figure 4.8 Flocculation occurred at top of the wastewater sample

4.5 Determination of best electrode materials combination

From the discussion above, Al-Fe was the best combination due to the greater positive charge, Al^{3+} production at Al anode and better bubbles production by Fe cathode. (Gomes et al., 2007) reported that removal efficiency of arsenic reach 98.8% by using Al-Fe electrodes at pH6. The concentration of arsenic dropped from 123.0 ppm to 1.43 ppm. In the study, it was also proved that the increase in electrolysis time improved the arsenic removal efficiency. On the other hands, as compared with Al-Al electrodes, the arsenic concentration decreased from 13.4 ppm to 0.34 ppm and reached 97.5% of efficiency removal which was slightly lower than Al-Fe electrodes.

Another research about the treatment of oil tanning effluent done by (Lakshmi & Sivashanmugam, 2013), the efficiency removal of COD reached 89% by using Al-Fe electrodes, however, Fe-Al electrodes recorded a slightly lower efficiency COD removal result which was 86%. (Chopra & Sharma, 2013) also recorded that Al-Fe was the best combination to remove COD, BOD and turbidity. The removal efficiency reached 81.51 % (TD), 74.36 % (COD) and 70.86 % (BOD) were achieved at electrode area of 160cm^2 and at 2.5 cm inter-electrode distance.

4.6 Metal dissolution of electrode material

By referring to Faraday's law, both aluminium and iron electrodes will undergo dissolution during electrocoagulation. The amount of Al dissolution was 0.102 g while Fe recorded 0.801 g. From the result, Al had higher amount of dissolution as compared with Fe which mean Al released more ion during the treatment. This also proved that Al was a better coagulant agent compared with Fe. Along with the Al dissolution, the Al grains were falling out and it was believed that normal corrosion phenomena had been occurred. However, the Al grains fell out did not help in coagulation process. Other than that, pH was a factor affected the metal dissolution. At anode, water oxidise to release photon and low pH value was obtained while at cathode, water reduce to form hydroxyl ions caused to higher pH value. Thus, pH was not a good value to determine the rate of dissolution, because it must differ considerably from the actual values on the electrodes surfaces (Rodrigo, 2005).

CHAPTER 5

CONCLUSION

5.1 Introduction

This chapter concluded the final finding of this project which main to achieve the objective which was to study the effect of electrode material on BOD, COD and TSS removal efficiency. Some recommendations were suggested to improve the performance of EC in order to increase its efficiency.

5.2 General Conclusion

Restaurant wastewater is wastewater from restaurant that contains dish cleaning waster, leftover food, oil and grease and so on. This wastewater contains high BOD, COD and TSS and causes pollution to environment if discharge into river without any treatment. EC is a good treatment method to treat restaurant wastewater. The objectives of this project were achieved by using different electrode materials (Al-Al, Fe-Fe, Al-Fe and Fe-Al) to remove BOD, COD and TSS from the wastewater. The highest removal efficiency was recorded by Al-Fe electrodes which reached 98% (BOD), 91.4% (COD) and 86.9% (TSS) followed by Fe- Al reached 80.7%, 96.7% and 63.0% of BOD, COD and TSS removal efficiency respectively. While, Fe-Fe electrodes achieved 80.6%, 95.7% and 61.5% efficiency removal of BOD, COD and TSS. Al-Al showed the worst removal efficiency of BOD, COD and TSS which were 70.9%, 85.7% and 64.4% respectively.

The reasons of different removal efficiency were due the different performance of aluminium and iron at anode and cathode. Aluminium was good at anode because it gave out trivalent ion Al^{3+} during oxidation but iron gave out divalent ion Fe^{2+} during oxidation. meanwhile, iron is good at cathode because it produced small and many bubbles during reduction. The bubbles removed the suspended solids by flocculation. Other than that, the amount of Al dissolution was 0.102 g while Fe recorded 0.801 g. this showed that Al had better production of trivalent ion which was good for neutralising colloid charge and helped in coagulation process.

5.3 Recommendation

EC is excellent in restaurant wastewater treatments, however, some improvements are needed to increase its efficiency in terms of energy consumption, environmental friendly and so on. The recommendations are stated as below:

1. Solar panel should be applied as power source to replace the DC power supply.
2. Hydrogen gas produced at cathode should be captured and stored for electricity generation purpose.
3. The current applied should be increase to reduce the treatment time.
4. Parameter of testing should be increased to observe from different perspective.
5. Batch scale result should be used in pilot plants.
6. pH of sample should be monitored to prevent metal dissolution.

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APPENDIX A

Result of BOD COD and TSS removal efficiency, % for four types of electrode materials

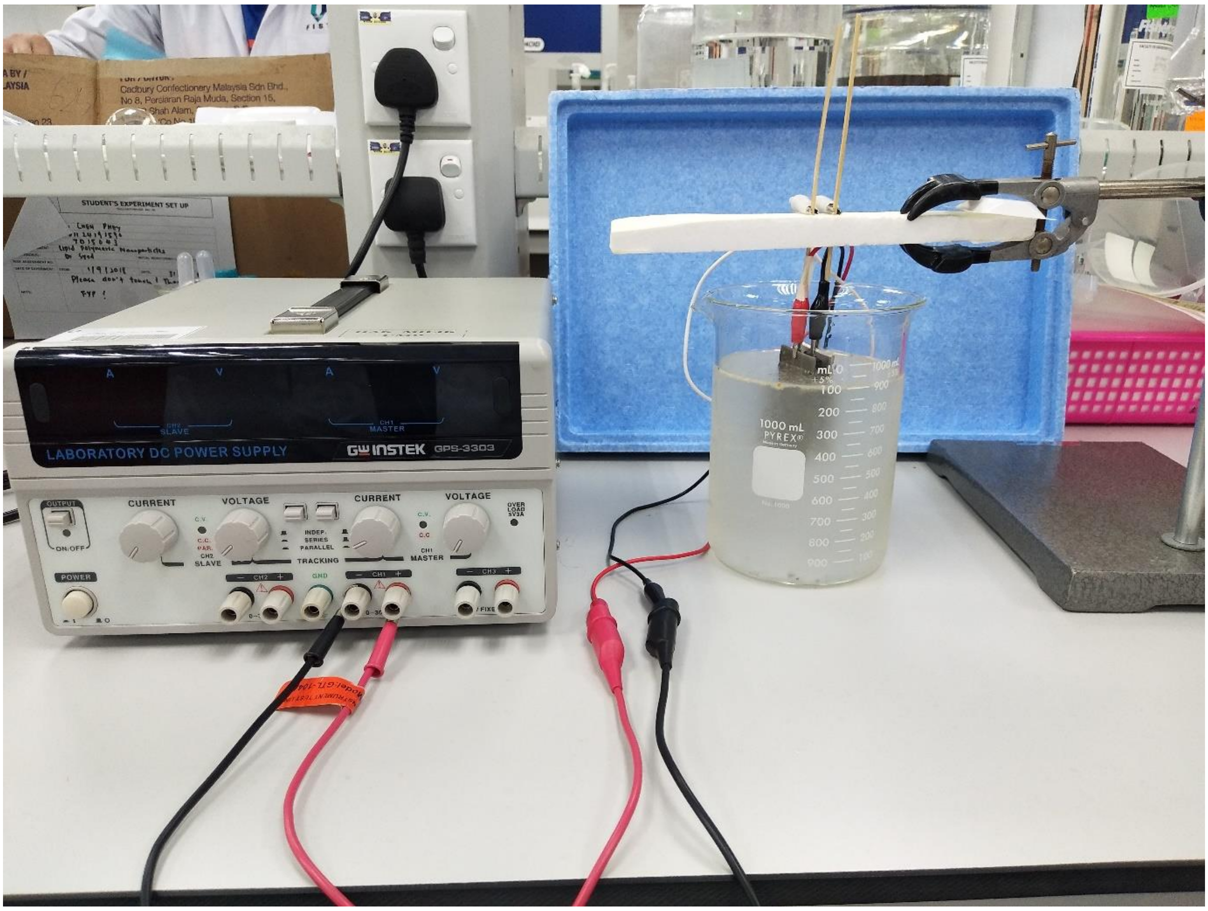
Duration, min	BOD removal efficiency, %			
	Al-Al	Fe-Fe	Fe-Al	Al-Fe
0	0	0	0	0
30	12.2	26.5	27.4	0.92
60	40.0	47.4	44.2	87.6
90	46.5	67.2	60.4	87.3
120	70.9	80.6	80.7	98.0

Duration, min	COD removal efficiency, %			
	Al-Al	Fe-Fe	Fe-Al	Al-Fe
0	0	0	0	0
30	36.4	60.6	31.1	80.3
60	54.0	70.1	68.3	81.9
90	79.3	88.0	88.1	91.4
120	85.7	95.7	96.7	92.3

Duration, min	TSS removal efficiency, %			
	Al-Al	Fe-Fe	Fe-Al	Al-Fe
0	0	0	0	0
30	6.67	13.2	51.9	66.2
60	62.2	35.2	53.1	80.8
90	64.8	52.7	59.2	81.5
120	51.1	61.5	63.0	86.9

APPENDIX B

Experiment Setup



APPENDIX C

TEST PARAMETER EQUIPMENTS AND APPARATUS

BOD

COD

TSS