TREATMENT OF PETROLEUM BASED INDUSTRY WASTEWATER USING ELECTROCOAGULANT ENHANCE BY CONVENTIONAL COAGULANT

HENRY YONG KIM FUONG

Thesis submitted in partial fulfilment of the requirements
for the award of the degree of
Bachelor of Chemical Engineering

Faculty of Chemical & Natural Resources Engineering
UNIVERSITI MALAYSIA PAHANG

JAN 2014

ABSTRACT

Electrocoagulation has been recognized positively to treat the wastewater from steam cleaners, textile manufacturing, mining operations, commercial laundry, municipal sewage system plants and palm oil industrial effluents. In this technology, metal cations are released into water through dissolving metal electrodes. Simultaneously, beneficial side reactions can help in removing flocculated material from the water. In present study, three steps of treatment will be carrying out to treat the petroleum based wastewater. The treatment includes preliminary settling process, coagulation process and electrocoagulation process. Preliminary settling is a natural process where no additional of chemical coagulant or additive to the samples. The settling time is set to be 24 hours for all the suspended solids to settle down. Preliminary settling process showed a big removal efficiency in total suspended solid (TSS) of the samples. The efficiency of removal for TSS during the preliminary settling process for sample T-1630, T-2300 and PPT are 0%, 72.44% and 75.14%. However, for coagulation process, the optimum dosage of coagulant required for three different samples were determined using jar test. There was huge reduction in chemical oxygen demand (COD) concentration after the coagulation process. The removal efficiency achieved for the coagulation process is 27%, 63% and 65% for sample T-1630, T-2300 and PPT respectively. Although the removal efficiency is higher, further treatment by using electrocoagulant is required to meet the discharge limit. The optimum voltage is determined and all the samples are treated with applied voltage of 100 V. The efficiency of removal for COD achieved during the electrocoagulation process for sample T-1630, T-2300 and PPT is 99.75%, 98.74% and 99.62% respectively which meet the permissible level, and save to discharge to the environment.

Key words: Coagulation, Discharge, Efficiency, Electrocoagulation, Settling, Wastewater

ABSTRAK

Electrocoagulation telah diiktiraf secara positif untuk merawat air sisa dari pembersih wap, pembuatan tekstil, operasi perlombongan, dobi komersial, kilang sistem kumbahan perbandaran dan minyak sawit efluen industri. Dalam teknologi ini, kation logam dilepaskan ke dalam air melalui larutan elektrod logam. Pada masa yang sama, tindak balas sampingan boleh membantu dalam menghapuskan bahan berbuku dari air. Dalam kajian ini, tiga langkah rawatan akan dijalankan untuk merawat sisa air yang dihasilkan oleh industri petroleum. Rawatan ini termasuk proses pengenapan awal, proses pembekuan dan proses electrocoagulation. Pengenapan awal adalah satu proses semula jadi di mana tiada tambahan koagulan kimia atau bahan tambahan kepada sampel. Masa yang ditetapkan untuk proses pengenapan adalah selama 24 jam supaya semua pepejal terampai untuk menetap. Proses pengenapan awal menunjukkan kecekapan penyingkiran besar dalam jumlah pepejal terampai (TSS) sampel. Kecekapan penyingkiran untuk TSS semasa proses pengenapan awal untuk sampel T-1630, T-2300 dan PPT adalah 0%, 72.44 % dan 75.14 %. Bagi proses pembekuan pula, dos yang optimum untuk proses koagulan diperlukan untuk tiga sampel yang berlainan telah ditentukan dengan menggunakan ujian balang. Terdapat pengurangan besar dalam permintaan oksigen kimia (COD) selepas proses pembekuan. Kecekapan penyingkiran dicapai untuk proses pembekuan ialah 27 % , 63% dan 65 % bagi sampel T-1630, T-2300 dan PPT masing-masing. Walaupun kecekapan penyingkiran sangat tinggi, rawatan lanjut dengan menggunakan electrocoagulant diperlukan untuk memenuhi had pelepasan. Voltan optimum ditentukan dan semua sampel akan dirawat dengan voltan pada 100 V. Kecekapan penyingkiran untuk COD dicapai semasa proses electrocoagulation bagi sampel T-1630, T-2300 dan PPT adalah 99.75 %, 98,74 % dan 99.62% dimana telah memenuhi paras yang dibenarkan, dan boleh dilepaskan kepada alam sekitar.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

c_i	pollutant concentrations after EC treatment eq(3.2)
c_o	pollutant concentrations before EC treatment eq(3.2)
$R\%$	removal efficiency eq(3.2)
W_A	weight of filter paper after filtration eq(3.1)
W_B	weight of filter paper before filtration eq(3.1)

Subscripts

µs	microsiemens
cm	centimetre
g	gram
L	litre
mg	miligram

LIST OF ABBREVIATIONS

ADMI	American Dye Manufacturers Institute
CC	Conventional Coagulation
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
EC	Electrocoagulation
EF	Electro flotation
NTU	Nephelometric Turbidity Units
PE	Population Equivalent
PPT	*Petronas Penapisan Terengganu*
QESB	Qualitest Engineering Sdn Bhd
TSS	Total suspended solid

LIST OF APPENDICES

1 INTRODUCTION

1.1 *Motivation and statement of problem*

The petroleum based industry is a collective term used to classify many different corporations that involve in activities directly related to the production of petroleum products. The corporations that involved in this industry cope with tasks that involve investigation for fresh reserves that can be used in the production of fuel oils, gasoline, and other essential petroleum-based products. Dealings that cope with the extraction of these resources as well as refining and even transporting oil products are also considered essential components within the industry.

The petroleum industry influences just about every facet of present life. In addition to providing fuels and lubricating compounds for private and public transportation, the industry also provides fuel for equipment used in the production of energy that helps to heat and cool public and private buildings. Furniture is often composed of petroleum by products. Even some forms of clothing contain fibers made from the leftovers of the petroleum refining process. From this perception, the petroleum industry affects the lives of consumers, even if they do not vigorously buying gasoline or oil for use in their vehicles. Hence, due to this, the production of petroleum based products increasing from day to day and same goes to the wastewater produce during the production. However, awareness toward the waste that produced during the production of products is so little. This includes the way to disposal the waste or the treatment that can be done before discharge the waste.

Jixiang Guo *et al.* (2011) claimed that wastewater from petroleum industry will contaminated the environment and increase the cost of petroleum production if it were discharged directly. The main components can be found in the petroleum based wastewaters are suspended solids, heavy metal ions, crude oil, barite, quartz, calcite and platioclase. The global petroleum industries have always faced with the problem of disposing of chemical wastes, by-products, and residuals. Increasing the demand of producing petroleum based products without pollution is the preferred model for industry.

Different countries have their own different discharge limits of wastewater. Their objective are same in which is to protect the local receiving waters (rivers and oceans) by regulating the industrial wastewater discharge.

Interpretation in brief for Standard A and B:

This regulation imposes a double standard upon effluent releases depending on where they are being released along the receiving river:

- In general, Standard A is applied if the point of discharge into the river is upstream from a water intake point for consumption or water catchment areas;
- In general, Standard B is applied if the point of discharge into the river is downstream from a water intake point for consumption or water catchment areas.

The discharge limits for industrial effluent based on environmental quality (industrial effluent) regulations, 2009 (Malaysia) as follow:

Table 1-1: Discharge limit for Industrial Effluent

Parameters	Standard A	Standard B
1. Aluminium mg/L	10	15
2. Ammoniacal Nitrogen mg/L	10	20
3. Arsenic mg/L	0.05	0.10
4. Barium mg/L	1.0	2.0
5. BOD5 at 20 ℃ mg/L	20	50
6. Boron mg/L	1.0	4.0
7. Cadmium mg/L	0.01	0.02
8. Chromium, Hexavalent mg/L	0.05	0.05
9. Chromium, Trivalent mg/L	0.20	1.0
10. Colour ADMI	100	200
11. Copper mg/L	0.20	1.0
12. Cyanide mg/L	0.05	0.10
13. Fluoride mg/L	2.0	5.0
14. Formaldehyde mg/L	1.0	2.0
15. Free Chlorine mg/L	1.0	2.0
16. Iron mg/L	1.0	5.0
17. Lead mg/L	0.10	0.5
18. Manganese mg/L	0.20	1.0
19. Mercury mg/L	0.005	0.05
20. Nickel mg/L	0.20	1.0
21. Oil and Grease mg/L	1.0	10
22. pH Value -	6.0-9.0	5.5-9.0
23. Phenol mg/L	0.001	1.0
24. Selenium mg/L	0.02	0.5
25. Silver mg/L	0.1	1.0
26. Sulphide mg/L	0.50	0.50

27. Suspended Solid mg/L	50	100
28. Temperature ℃	40	40
29. Tin mg/L	0.20	1.0
30. Zinc mg/L	2.0	2.0

***ADMI**-American Dye Manufacturers Institute

Regulation 12:

Acceptable conditions for the discharge of industrial effluent for parameter of chemical oxygen demand (COD):

Reference:

- The 'Seventh Schedule': COD limits for specific industrial types:
- The 'Sixth Schedule': location of catchment areas.
    a. Standard-A: into catchment areas listed in the 'Sixth Schedule'; i.e 80mg.L for most industries.
    b. Standard-B into other inland waters or Malaysian waters; i.e. 200mg/L for most industries.

Satisfactory disposal of wastewater, whether by surface, subsurface methods or dilution, is dependent on its treatment prior to disposal. Sufficient treatment is compulsory to prevent contamination of receiving waters to a degree which might restrict with their best or intended use, whether it is for water supply, recreation, or any other required purpose.

In the Operation of Wastewater Treatment Plants, Volume 1, it stated that wastewater treatment consists of applying known technology to improve or upgrade the quality of wastewater. Usually wastewater treatment will involve with collecting of the wastewater in a central, separated location such as the Wastewater Treatment Plant and exposing the wastewater to several treatment processes. Normally, due to large volumes of wastewater are needed to be treated, treatment processes are carried out on continuously flowing wastewaters mode rather than as batch or a series of periodic treatment processes in which treatment is carried out on parcels or batches of wastewaters. Since most of the wastewater treatment processes are continuous flow, certain operations, such as vacuum filtration is involving as it does storage of sludge, addition of chemicals, separation and removal or disposal of the treated sludge, are regularly handled as periodic batch operations. Some common technologies that use in wastewater treatment process are, activated sludge systems, electrocoagulation, sedimentation, reverse osmosis and thermal hydrolysis which widely used in the industry. The technology using in this studies is electrocoagulation.

R. Ramesh Babu *et al.* (2007) claimed that conventional coagulation has been used for decades to destabilized suspensions and to effect precipitation of soluble metal species, as well as other inorganic species from aqueous streams, thereby allowing their removal through sedimentation or filtration. Alum, lime, and/or polymers are the common chemical coagulants used. These processes, however, tend to generate large volumes of sludge with high bound water content that can be slow to filter and difficult to dewater. These treatment processes also tend to increase the total dissolved solids content of the effluent, making it unacceptable for reuse within industrial applications.

According to O.P.Sahu *et al.* (2013) coagulation can be achieved by chemical or electrical means. Chemical coagulation is becoming less practicable today because of the higher costs associated with chemical treatments. For an example, the large volumes of sludge generated and the hazardous waste categorization of metal hydroxides, huge costs of the chemicals required to effect coagulation.

Electrocoagulation (EC), is carrying out with the passing of electric current through water, has been prove that it's very effective in the removal of contaminants from water. Electrocoagulation systems have been in existence for many years (Dietrich, patented, 1906) using a variety of anode and cathode geometries, including plates, balls, fluidized bed spheres, wire mesh, rods and tubes.

The electrocoagulation process is based on effective precise principles involving responses of water contaminants to strong electrically induced redox reactions. This process is able to electrocute microorganisms in the water. It is also able to precipitate charged colloids and remove significant amounts of other ions, colloids and emulsions. When the system is in place, the operating costs including electric power, replacement of electrodes, pump maintenance and labour can be less than $1 per thousand gallons for some applications. Potential applications to agriculture and quality of rural life include removal of pathogen and heavy metals from drinking water and decontamination of food processing wash waters.

The principle for electrocoagulation is same as coagulation. Coagulation is one of the most significant physiochemical operations used in water treatment. This is a process used to destabilize the colloids and aggregation of smaller particles into larger particles. Water contaminants such as ions like heavy metal and colloids (organic and inorganics), are crucial held in solution by electrical charges. Schulze, in 1882, showed that colloidal systems could be destabilized by the addition of ions having a charge opposite to that of the colloidal (Benefield, et al, 1982). The destabilized colloids can be aggregated through coagulation process and subsequently removed by sedimentation and/or filtration.

Electrocoagulation can often neutralize ion and particle charges, thereby allowing contaminants to precipitate, reducing the concentration of contaminant below that possible with chemical precipitation, and can replace and/or reduce the use of expensive chemical agents such as metal salts or polymer.

1.2 Objectives

The following are the objectives of this research:

- To determine the efficiency of electrocoagulation process in treating petroleum based wastewater enhance by conventional coagulant.

1.3 Scope of this research

The following are the scope of this research:

i) To recognize the characteristic of the petroleum based wastewater.

ii) To control the dosage of coagulant to the wastewater.

iii) To determine the optimum voltage of the electrocoagulation process during the treatment.

iv) To identify the duration period for the wastewater treatment process in electrocoagulation process.

1.4 Main contribution of this work

The following are the contributions:

I. Reduce or replace the usage of conventional coagulant.

II. Figure out economic friendly parameters for electrocoagulant to operate.

III. Reduce the cost for treating wastewater.

IV. To support the treatment process in order to meet the discharge limit from Environmental Quality Act.

1.5 Organisation of this thesis

The structure of the reminder of the thesis is outlined as follow:

Chapter 2 provides a description of the overview of the electrocoagulant technology, parameters that affect the electrocoagulation process. Wastewaters obtained from the effluent system from two different petroleum based industry are the material use for the study. A general description on the history of the development of petroleum based industry, wastewater treatment process that commonly used in the industry and also the principle of electrocoagulation process. This chapter also provides a brief discussion on how the parameters such as pH, concentration of free chloride and characteristic of sample affecting the electrocoagulation process. The basic concepts and theory of coagulation in destabilized the colloids in contribute in to the treatment of wastewater.

Chapter 3 gives a review of various analyses applied on the wastewater sample before and after the treatment. The analysis include that been carrying out include determine the pH of the wastewater, COD, turbidity, temperature, and total suspended solid (TSS) to justify the removal efficiency of the electrocoagulation process. The removal efficiency is first been compared by using one particular sample but applied with different voltage. After determination of optimum voltage was done, comparison for the removal efficiency between samples treated with chemical coagulant and without additional of chemical coagulant is carrying out.

Chapter 4 is discussion on the result obtained from the experimental work. The characteristics of the wastewater obtained is determined at the beginning stage to figure out the parameters need to be focus on the treatment. Discussions on the various analyses on the efficiency of the removal by electrocoagulation process are also presented.

Chapter 5 draws together a summary of the thesis and outlines the future work which might be derived from the model developed in this work.

2 LITERATURE REVIEW

2.1 Overview

This study presents the experimental studies of electrocoagulation process toward the wastewater treatment process. This research is focus on the parameters which are able to affect the electrocoagulation process. The parameters include the pH of the wastewater that being treated with electrocoagulant, voltage applied during the electrocoagulation process, and the dosage of coagulant used. Some analysis will be carrying out to justify whether the electrocoagulation process is perform in the optimum conditions. The analyses include the pH, turbidity, chemical oxygen demand (COD), temperature, and total suspended solid. Experimental data that obtain is used to determine the efficiency for the electrocoagulant in removal of pollutant.

2.2 Introduction

This study presents a study of optimal parameters for electrocoagulation process to carry out in effective way in treating petroleum based wastewater. The optimal condition is justified by carrying out analysis on the COD of the wastewater. The experimental data obtain can be used to develop a condition where the electrocoagulant can operate effectively in treating wastewater.

2.3 Petroleum Industry

2.3.1 *History and Development of Petroleum*

Petroleum is an oily and flammable liquid that occurs naturally in deposits, usually underneath the surface of the earth. It is also known as crude oil. It consist principally a mixture of hydrocarbons, with traces of various nitrogenous and sulphurous compounds

During the past 600 million years, incompletely decayed plant and animal remains have become buried under thick layers of rock. It is believed that petroleum consists of the remains of these organisms but it is the small microscopic plankton organism remains that are largely responsible for the relatively high organic carbon content of fine-grained sediments like the Chattanooga shale which are the principle source rocks for petroleum. Among the leading producers of petroleum are Saudi Arabia, Russia, the

United States (chiefly Texas, North Dakota, Alaska, and California), China, Iran, Canada, the United Arab Emirates, Mexico, Brazil, Kuwait, Iraq, Nigeria, Venezuela, and Norway. The largest proven reserves are in the Middle East.

Petroleum has been known for a very long time. It was used in mortar, for coating walls and boat hulls, and as a fire weapon in defensive fighting. Native Americans used it in magic and medicine and in making paints. Pioneers bought it from the Native Americans for medicinal purpose and called it as Seneca oil and Genesee oil. In Europe it was raised from streams or holes in the ground, and in the early 19th century, small quantities of petroleum were made from shale. In 1815 several streets in Prague were lighted with petroleum lamps.

2.3.2 Composition and Refining of Petroleum

The physical properties and exact chemical composition of crude oil varies from one location to another. The different hydrocarbon components of petroleum are dissolved natural gas, gasoline, benzene, kerosene, naphtha, diesel fuel and light heating oils, heavy heating oils, and finally tars of various weights. The crude oil is usually sent from a well to a refinery in pipelines or tanker ships.

The hydrocarbon components are separated from each other by various refining processes. In fractional distillation process, petroleum is heated and sent into a tower. The vapours of the different components condense on collectors at different heights in the tower. The separated fractions are then drawn from the collectors and further processed into various petroleum products. One of the many products of crude oil is a light substance with little colour that is rich in gasoline. Another is a black tarry substance that is rich in asphalt.

As the lighter fractions, especially gasoline, are in the greatest demand, so-called cracking processes have been developed in which heat, pressure, and certain catalysts are used to break up the large molecules of heavy hydrocarbons into small molecules of light hydrocarbons. Some of the heavier fractions find eventual use as lubricating oils, paraffins, and highly refined medicinal substances such as petrolatum.

The modern petroleum industry began in 1859, when the American oil pioneer E. L. Drake drilled a producing well on Oil Creek in Pennsylvania at a place that later became Titusville. Numerous wells were drilled in the region. Kerosene was the main finished product. Today the world is seriously dependent on petroleum for motive power, lubrication, fuel, dyes, drugs, and many synthetics. The widespread use of petroleum has created serious environmental issues. The environmental issues brought by the widespread use of petroleum are acid rain, harm to the human health and other biological lives, and pollution to the surface and underground water sources. The unlimited quantities that are burned as fuels generate most of the air pollution in industrialized countries, and oil spilled from tankers and offshore wells has polluted oceans.

In the drilling oil process, corrosive acid wastes, toxic chemicals are intermittently released into rivers and lakes. Emissions of sulphur dioxide, nitrogen dioxide, carbon dioxide from power plants, burn high sulphur oil into the atmosphere. These together with injected particulate matter and unburned hydrocarbon undergo series of chemical reaction, resulting in dense characteristic of smoke. Sulphur dioxide is recognized as the third killer disease after active and passive smoking by the American Lung Association. Heat can be unnaturally added to the environment as a result of burning of forest and farmland vegetation as a result of the activities of the oil companies. This thermal pollution raises a greenhouse effect which can kill fish and other aquatic life, and can cause discomfort in habitable human environment.

2.4 Problem Encountered over the World

World has entered into a new era where sustainability is the main factor to encounter the challenges of exhaustion of our reserves and environmental upsets. Wastewater is not only one of the leading causes of irreversible damages to the environmental balances but also contributing to the depletion of fresh water reserves at this planet, generating threats to the next generation. Numerous industrial processes are conducted at the expense of plenty of fresh water which is exhausted as a wastewater, and need to be treated properly to reduce or eliminate the pollutants and achieve the purity level for its reutilization in the industrial process to promote sustainability. According to Muhammad Saleem *et al.* (2011), growing water shortage in Pakistan is compelling people to use the treated wastewater at least for landscape irrigation and plantation to augment available water resources. Water is important to sustain life on the biosphere. However, with the growing population and industrial development, its resources are becoming limited and contaminated. Due to the growing demand globally, more than a billion people lack access to sufficient good quality of water supply. Studies reported that one third of the world's population will suffer for severe water scarcity within the next 20 years (CGIAR, 2002). Problems are occurs as most of the fresh water resources are severely polluted with untreated industrial and municipal wastes (Malik, 2005).

2.4.1 Solution to Augment water Resources

Among other water management alternatives, the reuse of treated wastewater gained preferable attention (Saleem, 2009). The treated wastewater has several advantages over other sources of water, it minimizes pollution, expands groundwater resources by artificial recharge and it is a good nutrient source for landscape and farm irrigation (Saleem *et al.* 2000). While wastewater reuse in agriculture has been taking place for centuries, in countries like Mexico, Vietnam and China (Shuval *et al.*, 1986).

2.4.2 Limitations of Wastewater Reuse

Wastewater carries a wide spectrum of pathogenic organisms, which pose danger to agricultural workers, crop handlers and consumers (Al-Malack *et al*., 2002). High levels of nitrogen in wastewater may consequence in nitrate pollution of groundwater resources. Accumulation of heavy metals in soils and its uptake by plants is another risk supplementary with wastewater irrigation (Saleem, 2009).

2.5 Wastewater Treatment Process

Wastewater treatment, however, can also be organized or categorized by the nature of the treatment process operation being used; for example, physical, chemical or biological. A complete wastewater treatment system may consist of the application of a number of physical, chemical and biological processes to the wastewater. Examples of these treatment steps are shown below.

Table 2-1: Physical, chemical and biological wastewater treatment methods

Physical	Chemical	Biological
Sedimentation	Chlorination	Trickling filtration
Screening	Ion exchange	Oxidation ponds
Aeration	Neutralization	Lagoons
Filtration	Coagulation	Aerobic digestion

Flotation	Adsorption	Anaerobic digestion

Physical methods are processes where no gross chemical or biological changes are carried out and strictly physical phenomena are used to improve or treat the wastewater. Examples would be coarse screening stage to remove larger entrained objects and sedimentation or clarification. In the process of sedimentation, physical phenomena relating to the settling of solids by gravity force are allowed to operate. Usually this can be carrying out simply by holding a wastewater for a short period of time in a tank under quiescent conditions, allowing the heavier solids to settle, and removing the "clarified" effluent.

Sedimentation for solids separation is a very common process operation and is regularly employed at the beginning and end of wastewater treatment operations. While sedimentation is one of the most common physical treatment processes that are used to enhance the treatment process. Another physical treatment process consists of aeration that is, physically adding air, usually to supply oxygen to the wastewater.

Filtration is another common physical treatment that commonly used in industry. Here wastewater is passed through a filter medium to separate the solids. An example would be the use of sand filters to further remove entrained solids from a treated wastewater. Certain phenomena will occur during the sedimentation process and can be advantageously used to further improve water quality. Permitting greases or oils, for example, to float to the surface and skimming or physically removing them from the wastewaters is often carried out as part of the overall treatment process.

Chemical treatment is made up of the used of some chemical reaction or reactions to improve the water quality. The most commonly used chemical process is chlorination. Chlorine is a strong oxidizing chemical, which used to kill bacteria and to slow down the rate of decomposition of the wastewater. Bacterial kill is achieved when vital biological processes are affected by the chlorine. Another strong oxidizing agent that has also been used as an oxidizing disinfectant is ozone.

A chemical process that commonly used in many industrial wastewater treatment operations is neutralization. Neutralization consists of the addition of acid or base to adjust pH levels of the wastewater back to neutrality. Since sodium hydroxide is a base, it is sometimes used in the neutralization of acid wastewater.

Coagulation consists of the addition of a chemical that, through a chemical reaction, forms an insoluble end product which is flocs that helps to remove substances from the wastewater. Polyvalent metals are commonly used as coagulating chemicals in wastewater treatment and typical coagulants would include lime that can also be used in neutralization, certain iron containing compounds such as ferric chloride or ferric sulfate and aluminum sulfate.

There are some processes may actually be physical and chemical in nature. The use of activated carbon to "adsorb" or remove organics, for example, involves both chemical and physical processes. Processes such as ion exchange, which involves exchanging certain ions for others, are not used to any great extent in wastewater treatment.

On the other hand, biological treatment methods use microorganisms, mostly bacteria, in the biochemical decomposition of wastewaters to stable end products. More microorganisms or sludge are produced and a portion of the waste is converted to carbon dioxide, water and other end products. Generally, biological treatment methods can be divided into aerobic and anaerobic methods, based on the availability of dissolved oxygen.

The purpose of wastewater treatment is normally to remove contaminants from the wastewater enough solids to permit the remainder to be discharged to receiving water without interfering with its best or appropriate use. The solids which are removed are mainly organic but may also include inorganic solids. Treatment must also be provided for the solids and liquids which are removed from the wastewater treatment process that formed as sludge. Finally, treatment to control odors, to retard biological activity, or destroy pathogenic organisms may also be required.

Peter Holt *et al.*, 2006 claimed that coagulation and flocculation are traditional methods for the treatment of polluted water. In processes, coagulating agents for example alum or ferric chloride and other additives such as polyelectrolytes are dosed to produce larger aggregates, which can be separated physically. This is a multi-stage process that requires large land area and a continual supply of chemicals. On the other hand, electrocoagulation is an extremely effective wastewater treatment system. During the electrocoagulation process, pollutants are being removed and hydrogen gas is produced simultaneously as revenue to compensate the operational cost (Nasution, M.A., *et al.*, 2011).

Electrocoagulation has been recognized positively to treat the wastewater from steam cleaners, textile manufacturing, pressure washers, metal plates, mining operations, meat and poultry processors, commercial laundry, municipal sewage system plants and palm oil industrial effluents. In this technology, metal cations are released into water through dissolving metal electrodes. Simultaneously, beneficial side reactions can help in removing flocculated material from the water. However, there are also adverse side reactions, such as deposition of salts on the electrodes surface, which may cause deterioration with removal efficiency after long period of operation. As in the case of chemical coagulation in metal salts, aluminium or iron cations and hydroxides are the active compounds in electrocoagulation. Chemical coagulation and EC have fundamentally similar destabilization mechanisms of colloidal particles and it is therefore important to go through the theory of colloid destabilization with metal salt coagulants, because chemical coagulation has been studied more comprehensively than EC.

2.5.1 Basic concepts and theory of coagulation and flocculation with hydrolysing metal salts

Pollutants in wastewaters are typically colloidal particles, which are not easily eliminated with usual filtration sedimentation or flotation due to their stability in water. These colloidal particles have special properties due to their small size and large total surface area. Colloid is a microscopic particle, typically having at least one dimension in the range of 1 nm to 10 µm, which is spread throughout the other substance. The medium where particles are dispersed can be gas, liquid or solid. The combined surface area of colloids in dispersions is large due to their small size and therefore surface properties play an important role in their characteristics. Natural water and typical wastewater are hetero dispersions, having a extensive variety of particles with different particles sizes.

Stability and destabilization of colloids in solutions is the result of their surface charge. Surface immersed into a solution can attain a charge by ionization of surface groups, by ion adsorption, by dissolution of ionic solids or by isomorphous substitution. Many surfaces contain ionisable functional groups, such as –OH, -COOH or $–NH_2$. Therefore, surface charge depends on the ionization of these functional groups and consequently on the pH of the solution.

When a charge forms on the surface, it also affects the ions in the surrounding solution. The ions of opposite charge are attracted towards the surface, whereas the ions of the same charge repelled from the surface. This separation of charges on the particle surface results in the formation of electrical double layer (EDL) as showed in figure below.

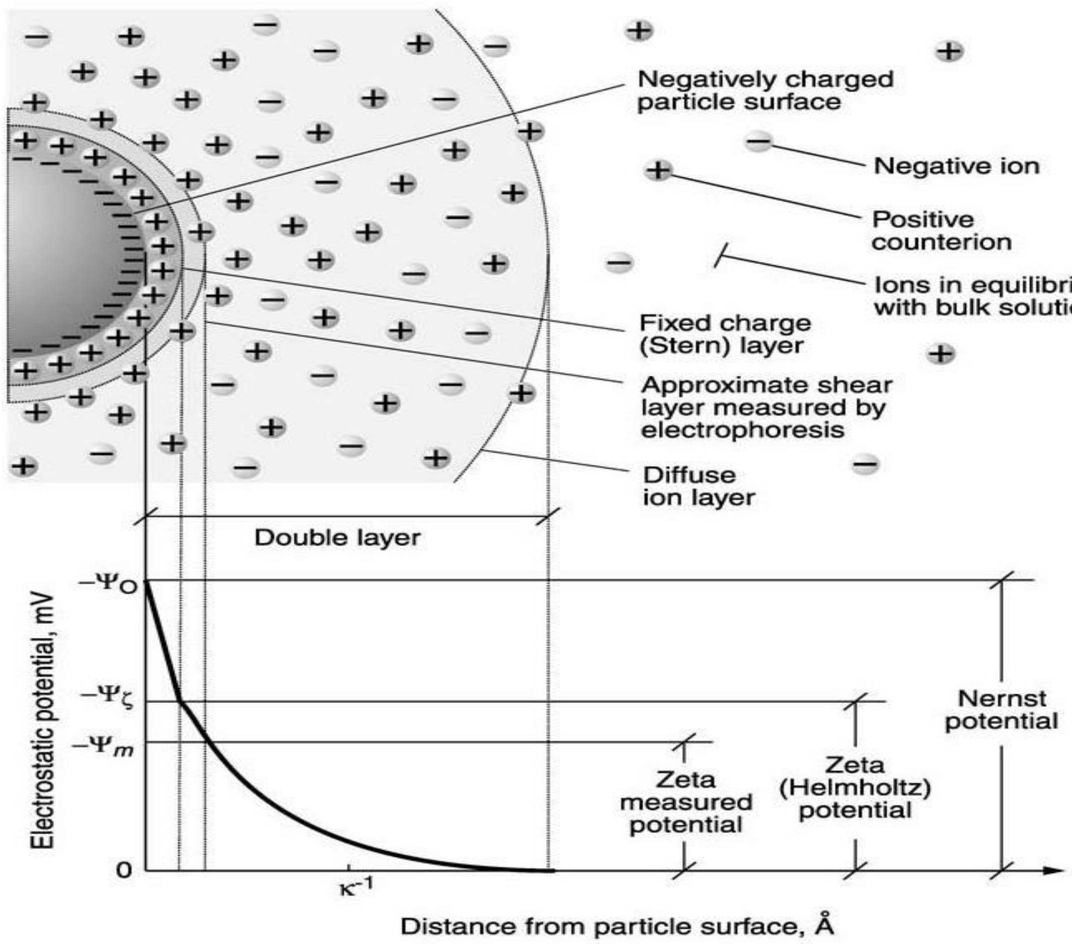

Figure 2-1: Conceptual representation of the electrical double layer

2.5.2 Stability of colloids in aqueous solutions

Colloids are said to be stable in aqueous solutions when their accumulation or sedimentation is so slow that they make virtually stable dispersions. This aspect is important when considering wastewater treatments because there particles cannot be removed by sedimentation in a reasonable period of time. Stability or distability of