REMOVAL MERCURY FROM WASTEWATER BY ELECTROCOAGULATION USING IRON PLATE AS ELECTRODE

BY

MOHD AMIRUL HAKIM BIN HAMIDI

Thesis submitted in fulfillment of the requirements

for the award of the degree of

Bachelor of Chemical Engineering in Chemical Engineering

Faculty of Chemical Engineering and Natural Resources

UNIVERSITI MALAYSIA PAHANG

JANUARY 2013

SUPERVISOR DECLARATION

I hereby declare that I have been read through this project report and to my opinion this report is adequate in term of scope and qualification for the purpose of awarding the degree of Bachelor of Chemical Engineering.

Signature : ______________________________

Supervisor : Dr Mazrul Nizam Bin Abu Seman

Position :

Date :

STUDENT DECLARATION

I declare that this report entitle “Mercury removal from Wastewater by electrocoagulation using Iron Plate as Electrode” is the result of my own research except this as cited in references. The report has not been accepted for any degree and is not currently submitted in candidature of any other degree.

Signature : ______________________________

Name : Mohd Amirul Hakim Bin Hamidi

ID Number : KA 09111

Date :

ACKNOWLEDGEMENT

Alhamdulilah, grateful to Allah the most kindness and merciful God. With His bless I had finished my final year project. First of all I sincerely would like to thank to my supportive supervisor Dr Mazrul Nizam Bin Abu Seman for all his support and guidance on me during undergo the project research. I also want to thank to Mr Fazli who teach me how to use Electrocoagulant OT-1 model. Without him may be I do not know how start my research.

Not forget to my beloved parents and friend who encourage and help me directly or indirectly in order to the successful of this research. Last but not least I hope this research will be beneficial to the society and may be become references for the other future study.

ABSTRACT

Electrocoagulation is the removal process that based on electricity which used electrolysis concept. This process can remove contaminant like mercury which cannot be removed through filtration. This technique is economic and environmental friendly for wastewater treatment. Research studied was performed using synthetic mercury to determine the efficiency of mercury removal using this process. The objective of this research is to investigate the efficiency of mercury removal using iron electrode using different parameters including flow rate, charge loading and distance between electrodes. Electrocoagulation OT-1 model was used to perform the experiment and conductivity meter was used to perform the analysis. After all the analysis were performed its shows significant result which is about 90.10% of mercury successfully removed from the synthetic mercury solution. The highest flow rate 160 L/h and longest distance between electrodes 5cm contributed to the result of 90.10% removal of mercury from synthetic mercury solution. The highest charge loading also play importance role on removal of mercury.

ABSTRAK

Electrocoagulation adalah proses penyingkiran yang berdasarkan elektrik yang menggunakan konsep elektrolisis. Proses ini boleh mengeluarkan bahan cemar seperti raksa yang tidak boleh dikeluarkan melalui penapisan. Teknik ini adalah ekonomi dan mesra alam untuk rawatan air sisa. Penyelidikan telah dilakukan menggunakan raksa sintetik untuk menentukan kecekapan penyingkiran merkuri menggunakan proses ini. Objektif kajian ini adalah untuk menyiasat kecekapan penyingkiran merkuri menggunakan elektrod besi menggunakan parameter kadar aliran, muatan cas dan jarak antara elektrod. Model Electrocoagulation OT-1 telah digunakan untuk melaksanakan eksperimen dan meter kekonduksian telah digunakan untuk melaksanakan analisis. Selepas semua analisis telah dijalankan menunjukkan hasil penting yang kira-kira 90, 10% merkuri berjaya dikeluarkan dari sintetik merkuri. Aliran tertinggi kadar 160 L / h dan jarak terpanjang antara elektrod 5cm menyumbang kepada keputusan 90.10% merkuri Berjaya dikeluarkan dari sintetik merkuri. Pengaliran caj tertinggi juga memainkan peranan yang penting penyingkiran merkuri.

TABLE OF CONTENT

TITLE PAGE **PAGES**

CHAPTER 1 **INTRODUCTION**

CHAPTER 2 LITERATURE REVIEW

CHAPTER 3 METHODHOLOGY

CHAPTER 4 RESULT AND DISCUSSION

CHAPTER 5 CONCLUSION AND RECOMMENDATION

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS/ABBREVIATION

SYMBOL	**DESCRIPTION**
Hg	Mercury
$HgCl_2$	Mercury Chloride
NaCl	Sodium Chloride
HCl	Hydrochloric Acid
H_2SO_4	Sulphuric Acid
ppm	Part per million
C_o	Initial Concentration
C	Final Concentration
A	Ampere
V	Voltage

CHAPTER 1

INTRODUCTION

1.1 Background of study

Every industry in the world whether it is chemical, agriculture, manufacturing or any things else will produce its own domestic waste which can contribute to the water pollution. Water is one of the essential elements that very important for human being. One of the dangerous elements that may contain water pollution is heavy metal. Usually heavy metal is one of the sources of inorganic pollutants that always found in the industrial that mostly produced through waste water. Heavy metal can include elements lighter than carbon and can exclude some of the heaviest metals. Heavy metals occur naturally in the ecosystem with large variations in concentration. In organic pollutants and its particular heavy metals create a serious threat for the environment. These heavy metals can cause serious long term diseased such as teratogenic and carcinogenic. *(*Hyman*, et. al, 2004).*

One of the dangerous heavy metals is mercury. Mercury is mutagenic, carcinogenic, teratogenic and can promote tyrosinemia. Impairment of pulmonary and kidney function, chest pain and dyspnousea can be caused by high concentration of mercury. *(*Fu-shenzhang*, et. al, 2004).* The manufactures that produce heavy metal as their waste are clinical thermometer, paints that contain mercury sulphate, battery and accumulator that made up of mercury oxide. *(*Wesenbececk, *et. al*, *2006).* The most famous example of acute mercury contamination occurred in fishing villages along the shore of Minamata Bay, Japan. Chisso, a chemical company located near the bay, used mercury sulphate and mercury chloride as catalysts in the production of acetaldehyde and vinyl chloride. Wastewater from the plant was discharged into Minamata Bay and contained both inorganic mercury and methyl mercury. The methyl mercury originated mainly as a side product of the acetaldehyde production process. Methyl mercury accumulated in the fish and shellfish in the bay and in local people who ate the fish and shellfish. The result was a form of mercury poisoning that is now known as Minamata disease. *(*Weinberg*, et. al, 2010).*

1.1.1 Industrial aspects

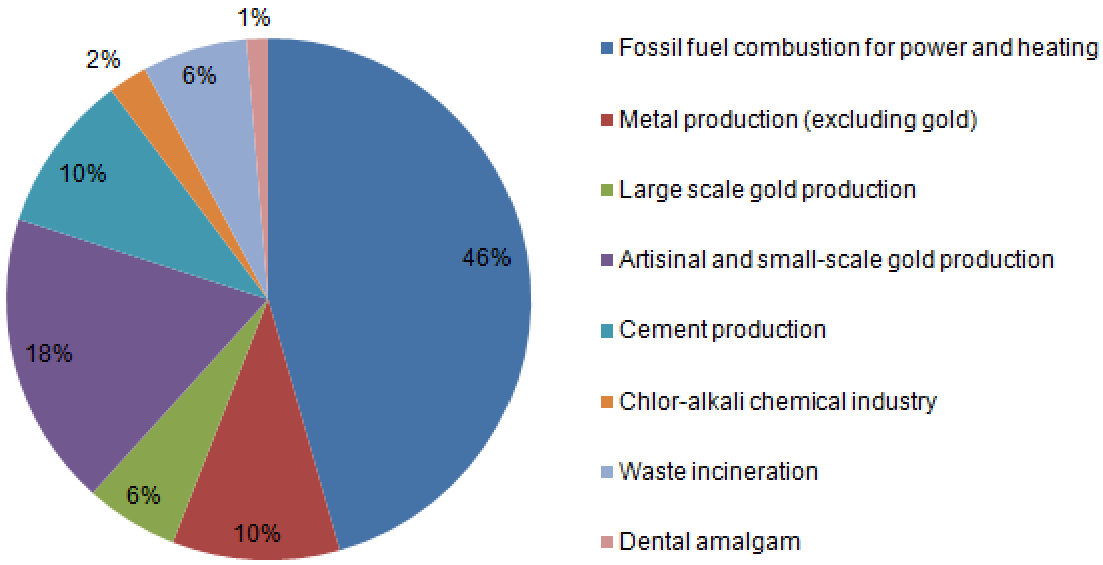
In recent years, there has been a growing need to eliminate hazardous pollutants from water. It is because many industries involved mercury on their product. Mercury is used as a component in many consumer products, like thermometers, batteries, electronic devices and many automotive parts, and can escape as a pollutant when these products are manufactured, broken during use, or most importantly, handled and disposed of at the end of the product's useful life. It can also be used as an additive to cosmetics and antiseptics, often exposing consumers unknowingly and unnecessarily. Incinerators burning mercury wastes, including discarded products, can release significant quantities of mercury unless they are equipped with appropriate mercury capture devices. Likewise, the recycling of scrap metal (secondary smelting) can release mercury from auto parts like light switches, if proper care is not taken to remove the mercury before smelting and/or mercury capture devices are not installed on the smelter.

Because of the serious effect of mercury, regulation of mercury pollution has finally begun to phase in among the largest emitters despite long delays and repeated attempts to weaken mercury regulations under the Clean Water Act. The Environmental Protection Agency finalized clean air safeguards to reduce toxic pollution, including mercury, from:

- cement plants in 2010
- power plants in 2011,
- gold mining in 2011, and
- industrial boilers in 2011,

New standards were proposed for the chlorine chemicals industry in 2011. Mercury emissions are slated to go down 80 percent by 2016 compared to 1990 levels, due to these US EPA regulations. *(*Natural Resources Defense Council, *http://www.nrdc.org/health/effects/mercury/sources.asp)*

This the pie chart of the industry that involved with the mercury waste.



Source: AMAP/UNEP, 2008. Technical Background Report to the Global Atmospheric Mercury Assessment. Arctic Monitoring and Assessment Programme/UNEP Chemicals Branch. Page 39.

Figure 1.1: Industries that involved with mercury waste

Source: (AMAP/UNEP Chemicals Branch Page 39, 2008)

1.1.2 Electrocoagulation

Electrocoagulation is a complex process, with a multitude of mechanisms operating synergistically to remove pollutants from the water. A wide variety of opinions exist in the literature for both the key mechanisms and the best reactor configurations. Design variations include a fluidised-bed reactor employing pellets, bipolar electrodes, mesh electrodes, as well as simple plate electrodes. There is certainly no dominant ‘electrocoagulation reactor’ in use. Reported operating conditions and performance mirror the wide variation in design, with reactors invariably being ‘tuned’ to best suit a specific application. These empirical approaches invariably prove the viability of the technology, but singularly fails to fully capitalise on its potential. This is due to a lack of fundamental understanding of the system and hence the inability to accurately predict performance.

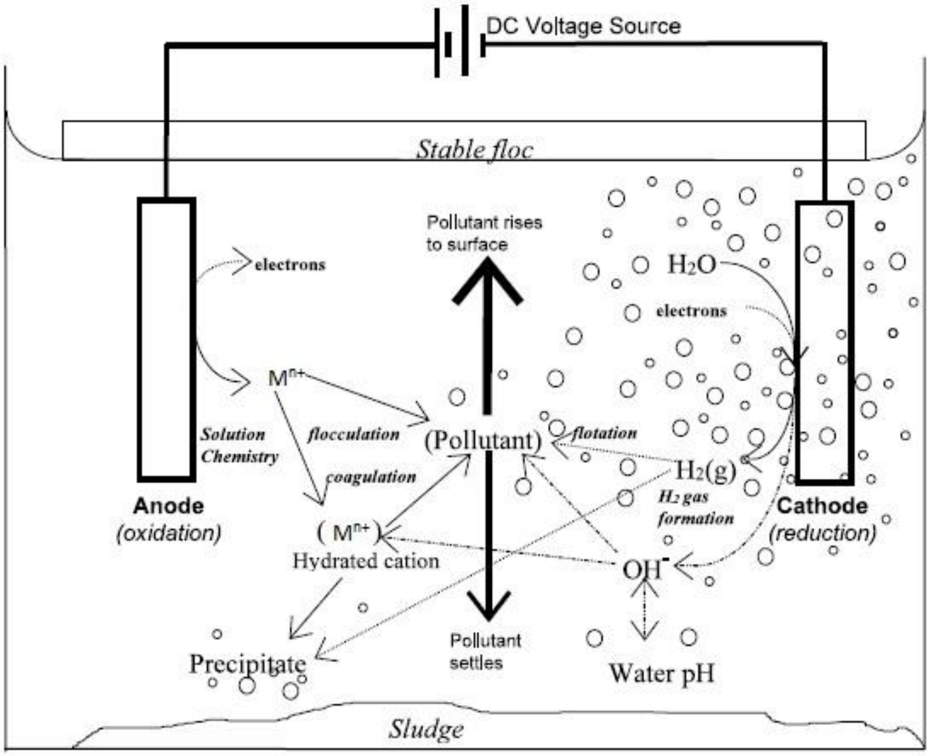


Figure 1.2 Interaction occurring within an electrocoagulation reactor

*Sources: (*Holt, *et. al, 2002)*

Figure 1.2 shows the interdependent nature of the electrocoagulation process. A sacrificial metal anode is used to dose polluted water with a coagulating agent. Simultaneously, electrolytic gases (mainly hydrogen at the cathode) are generated. It is possible to identify three separate categories of mechanistic process which are electrochemistry, coagulation, and hydrodynamics. These are the basis form of electrocoagulation process. The fact that these processes are difficult to investigate separately in an operational reactor goes some way towards explaining the lack of a detailed technical literature on electrocoagulation.

1.2 Problem Statement

Mercury is the one of contaminant in petrochemical wastewater. In petrochemical sector and industries, the production of mercury is very large every year. Mercury is heavy metal compound, so it is very dangerous to the human and our ecosystem. The production of mercury not only dangerous to the human and ecosystem but it also gives more problems to our equipment. Coagulation of Petrochemical waste is an important process in water treatment that helps to produce clear, finished water which is aesthetically acceptable to the consumer. Much of the suspended matter in water is colloidal (1 mm to 1 m) and negatively charged. Because of their large surface area and electrical charge, colloidal particles settle very slowly. Iron salts are used to neutralize these surface charges and to cause the colloids to combine and become large enough so that they will readily settle. But the conventional method which is chemical coagulation used to reducing the effects caused by the presence of mercury will increase the amount of sludge production. Other problems are permanent water hardness, water salts like sodium, annual high operation costs, sediment formation on membrane, which require an effluent post treatment and disposal of residual sludge. Before this, the scientist show that mercury cannot be degraded either biologically or chemically, and besides, it can be converted into more toxic compounds in the environment *(*Wang *et. al, 2004).* Therefore to overcome this problem, new alternative method like electrocoagulation may help to improve removal of mercury from petrochemical waste water.

1.3 Objective

The objective of this undergraduate research project is to remove mercury from the synthetic wastewater by electrocoagulation using iron as electrode and to investigate the efficiency of the electrocoagulation process in removal of mercury from wastewater by manipulating a few parameters..

1.4 Scope of study

The scope of study is to investigate the effect of parameter on mercury removal. Therefore, the scopes of study are:

i. Study the effect of charge loading efficiency on removal of mercury ion.
ii. Study the effect of flow rate efficiency on removal of mercury ion.
iii. Study the effect of distance between electrodes efficiency on removal of mercury ion.

1.5 Significant of study

Many problems are arises from chemical coagulant method such as permanent water hardness, water salts like sodium, annual high operation costs, sediment formation on membrane, which require an effluent post treatment and disposal of residual sludge while electrocoagulation utilizes methods that precipitate out large quantities of contaminants in one operation; the technology is the distinct economic and environmental choice for industrial, commercial and municipal waste treatment.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview of Mercury

Mercury is a natural element whose chemical symbol is Hg. This abbreviation comes from the Greek word hydrargyrum, which means liquid silver. In its pure form, mercury is a silvery-white metal that is liquid at standard temperature and pressure. In different contexts, pure mercury is often called quicksilver, metallic mercury, or liquid mercury. Most commonly, however, pure mercury is called elemental mercury. *(www.ipen .org)*

Because elemental mercury has high surface tension, it forms small, compact, spherical droplets when it is released into the environment. Although the droplets themselves are stable, the high vapor pressure of mercury compared with other metals causes the mercury to evaporate. In an indoor setting, mercury can quickly become an inhalation hazard. Outdoors, elemental mercury vaporizes and enters the atmosphere.

Elemental mercury can be produced for human use from an ore called cinnabar, which contains high concentrations of mercury sulfide. Elemental mercury can also be produced as a by-product from the mining and refining of metals such as copper, gold, lead, and zinc. Mercury can also be recovered by recycling operations and is sometimes removed from natural gas or other fossil fuels.

It has been estimated that approximately one-third of the mercury circulating in the global environment is naturally occurring and approximately two-thirds was originally released into the environment as a result of industrial and other human activities. The amount of mercury that is circulating in the world's atmosphere, soils, lakes, streams, and oceans has increased by the start of the industrial era. As a result, levels of mercury in our environment are dangerously high.

Several kinds of human activities release mercury into the environment. Mercury is present in fossil fuels, metal ores, and other minerals. When coal is burned, much of its mercury content enters the environment. Mining and refining metal ores and the manufacture of cement also release mercury into the environment.

Table 2.1: Properties of mercury

Some Properties of Elemental Mercury	
Property	**Value**
Atomic Weight	200.59
Atomic Number	80
Melting Point	-38.87°C
Boiling Point	356.58°C
Vapor Pressure at 25°C	2×10^{-3} mm Hg
Solubility in Water at 25°C	20–30 µg/L
CAS Registry Number	7439-97-6
Mass	13.5336 gm/cc

2.1.1 Forms of Mercury

Most mercury in the atmosphere is in the gaseous state, but some is attached to particulate matter. Gaseous mercury is mostly elemental mercury, but a small percentage has been oxidized into mercury compounds such as mercury chloride and mercury oxide. Pure mercury vapor, also called gaseous elemental mercury (GEM), has very low water solubility and is very stable in the atmosphere, with an estimated residence time of between six months and two years. This stability enables elemental mercury to undergo long range transport and causes GEM concentrations to be fairly uniform in the atmosphere.

However, mercury is usually found in inorganic or organic forms. In the inorganic form, it usually exists in various physical states: liquid (HgO) or solid (salts of Hg^{2+}, Hg^{2+} ions or oxide). However, inorganic mercury can combine with organic compounds to give organometallics, and sometimes methyl mercury under the action of bacteria for instance. In this final form, mercury is much more toxic and labile compared to its free form. In general, mercury contamination is favored by its high volatility which can make its inhalation through air, its high reactivity readily allows mercury to combine with various other elements, leading to quite stable species, and that can accumulate in sea products.

Elemental mercury is initially released into the atmosphere, captured by precipitation and ultimately deposited in the sediments of lakes and oceans. This process leads to the second type of the transport and distribution of mercury. It involves the deposition of mercury in the sediments of lakes and oceans and its transformation to a methylated species by anaerobic bacteria. The amount of methyl-mercury produced by anaerobic bacteria may be decreased by demethylation reactions and volatilization of dimethylmercury.

2.1.2 Sources of Mercury

Mercury Mining

The largest use of mercury during the sixteenth to eighteenth centuries was for the production of silver and gold in Latin America, and this use released enormous quantities of mercury into the global environment. Most of this silver and gold was shipped back to Spain and Portugal, where it became a major contributor to rapid economic expansion in Western Europe.

The nineteenth century saw a large boom of mercury mining in North America for use by gold rush miners in California and then northern Canada and Alaska. This gold production was an important contributor to economic expansion in North America. Nineteenth-century gold booms also occurred in Australia and in other countries. Large quantities of mercury from the gold and silver mining of earlier centuries remain in the environment and continue to be a source of harm.

Operations that mine mercury ores and refine them into elemental mercury release a large amount of mercury vapors into the air and are thus also a direct and significant source of mercury pollution. One study found atmospheric mercury concentrations around an abandoned mercury mine in China to be several orders of magnitude higher than regional background sites. A study of human exposure to mercury from eating rice grown in a district near mercury mines and smelters found high exposure, even when compared with districts near zinc smelters and heavy coal-based industries. Researchers in California measured significant amounts of mercury leaching into a creek flowing past a long-abandoned mercury mine site. This and preliminary results from other mine sites indicate that inoperative mercury mines are major sources of mercury pollution to water bodies, and they also, in turn, remain continuing sources of atmospheric mercury emissions as well.

Producing Elemental Mercury as a By-Product in Nonferrous Metals Refining

Elemental mercury is also sometimes produced as a by-product when various metal ores are refined. Mercury is found in trace quantities in most nonferrous metal ores such as zinc, copper, lead, gold, silver, and others. Until recently, the mercury content of these ores would be released into the environment as part of the waste streams generated during mining and refining. In recent years, however, some refiners have started to recover mercury from their wastes and produce elemental mercury for sale on domestic or international markets.

Elemental Mercury from Natural Gas

Natural gas contains trace quantities of mercury that is released into the environment when the gas is burned. In some areas including countries bordering the North Sea, Algeria, Croatia, and others the mercury concentrations in the gas are particularly high, and processors in these areas often remove mercury from their gas. It is estimated that 20–30 metric tons of mercury are recovered yearly from natural gas wastes in the European Union. Producers of liquid natural gas (LNG) remove mercury from natural gas before cooling it. Otherwise, the mercury present in the gas will damage the aluminum heat exchangers used in natural gas liquefaction plants. This typically requires reducing the mercury content of the natural gas to below 0.01 micrograms of mercury per normal cubic meter of natural gas.

Mercury Recycling and Recovery

Most of the elemental mercury that is recovered by recycling comes from industrial processes that use mercury or mercury compounds. In some cases, the mercury that is recovered is reused by the industry. In some cases, it goes onto the market. And in some cases, agreements have been reached to remove the recovered mercury from the market and place it in permanent storage. The largest source of recycled or recovered mercury is the chlor-alkali industry. This industry produces chlorine gas and alkali (sodium hydroxide) by a process that applies electrolysis to saltwater. Some chlor-alkali plants use a mercury-cell process in which mercury is used as the electrolysis cathode. Mercury-cell chlor-alkali plants consume large quantities of mercury and are very polluting. Fortunately, the trend in recent years has been to phase out many of these mercury-cell plants in favor of other processes that do not use mercury. A single mercury-cell plant may contain hundreds of tons of elemental mercury for use in production and may have even more mercury in its warehouses to replenish lost mercury. When a mercury cell is decommissioned, much of this mercury can be recovered.

2.2 Health Effect

Mercury can give many bad effect to the human as well as environment. Mercury that usually exposed to human is methylmercury. It can cause many dangerous and harmful disease which related to mutation to human. Animal and ecosystem also can be affected by mercury.

2.2.1 Human Effect

Elemental (metallic) mercury and all of its compounds are toxic, exposure to excessive levels can permanently damage or fatally injure the brain and kidneys. Elemental mercury can also be absorbed through the skin and cause allergic reactions. Ingestion of inorganic mercury compounds can cause severe renal and gastrointestinal damage. Organic compounds of mercury such as methyl mercury are considered the most toxic forms of the element. Exposures to very small amounts of these compounds can result in devastating neurological damage and death. For fetuses, infants and children, the primary health effects of mercury are on neurological development. Even low levels of mercury exposure such as result from mother's consumption methylmercury in dietary sources can adversely affect the brain and nervous system. (Department of Health and Human services, National Institute of Health*)*.

Sources of exposure are widespread and include mercury vapors in ambient air, ingestion via drinking water, fish, vaccines, occupational exposures, home exposures including fluorescent light bulbs, thermostats, batteries, red tattoo dye, skin lightening creams, and over-the-counter products such as contact lens fluid and neosynephrine, dental amalgams, and more. Amalgam exposure is estimated to be from 3 to 17 micrograms per day from slow corrosion, chewing, brushing and grinding. The toxicokinetics of mercury were reviewed. Absorption is about 80% for mercury vapor and nearly 100% for oral absorption. It is primarily distributed in the kidneys and brain and readily transferred to the fetus via the placenta. It is eliminated via the urine, feces, expired air, and breast milk. The major toxicity is from mercury's ability to covalently bind to sulfhydryl groups of enzymes in microsomes and mitochondria and other enzyme binding sites including carboxyl, amide, amine, and phosphoryl groups. Clinical manifestations were reviewed, including the historical context of mercury poisoning epidemics such as the Minamata Bay exposures in Japan, acrodynia or pink disease in children from calomel (Hg Cl) used in teething powder, mad hatter syndrome or erethism, and methylmercury fungicide grain seed exposures in Iraq and Pakistan. *(*Ratard *et. al, 2004)*

Major sources of mercury exposure include dental amalgams (vapor), fish (methylmercury), and vaccines (ethylmercury). Toxic effects, spread across a broad spectrum of diseases including autism, Alzheimer's disease, ALS, multiple sclerosis, Parkinson's disease, neurodevelopmental diseases, nephrotoxicity, and cancer. Reporting on the review in the New England Journal of Medicine, reported that the fetal brain is more susceptible than the adult brain to mercury-induced damage including the division and migration of neuronal cells and disruption of the cytoarchitecture of the developing brain. *(*Nash *et. al, 2004)*

2.2.2 Environmental Effects

In the environment, sulfate-reducing bacteria take up mercury in its inorganic form and through metabolic processes convert it to methylmercury. Sulfate-reducing bacteria are found in anaerobic conditions, typical of the well-buried muddy sediments of rivers, lakes, and oceans where methylmercury concentrations tend to be highest. Sulfate-reducing bacteria use sulfur rather than oxygen as their cellular energy-driving system. One hypothesis is that the uptake of inorganic mercury by sulfate-reducing bacteria occurs via passive diffusion of the dissolved complex HgS. Once the bacterium has taken up this complex, it utilizes detoxification enzymes to strip the sulfur group from the complex and replaces it with a methyl group:

Equation 2.1: $HgS \xrightarrow{\text{bacteria}} CH_3Hg(II)X + H_2S$

Upon methylation, the sulfate-reducing bacteria transport the new mercury complex back to the aquatic environment, where it is taken up by other microorganisms. (http://scifun.chem.wisc.edu/chemweek/gasemit/gasemit.html)

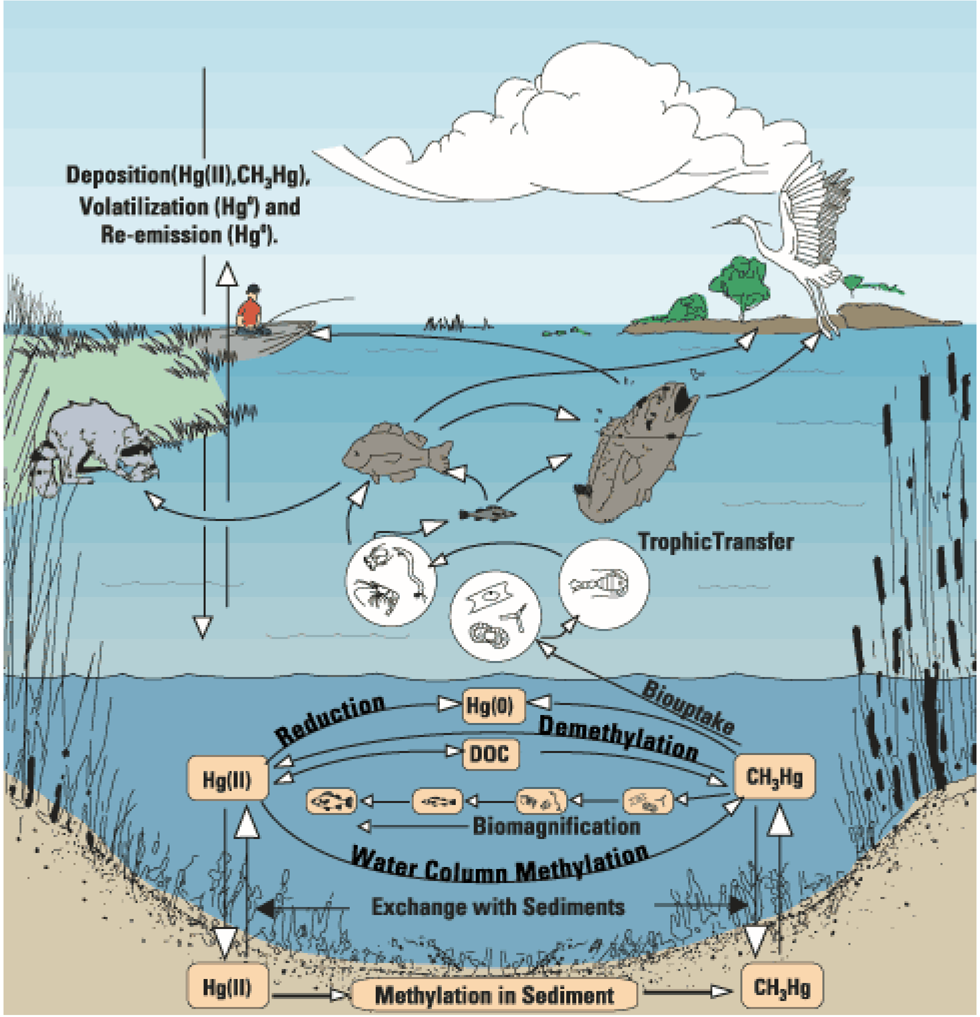


Figure 2.1 Aquatic mercury cycle

(US Geological Survey, *http://www.cfsan.fda.gov/~dms/admehg3.html).*

The major source of methylmercury exposure in humans is consumption of fish, marine mammals, and crustaceans. Once inside the human body, roughly 95% of the fish-derived methylmercury is absorbed from the gastrointestinal tract and distributed throughout the body. Uptake and accumulation of methylmercury is rapid due to the formation of methylmercury-cysteine complexes. Methylmercury is believed to cause toxicity by binding the sulfhydryl groups at the active centers of critical enzymes and structural proteins. Binding of methylmercury to these moieties constitutively alters the structure of the protein, inactivating or significantly lowering its functional capabilities.

Over forty states in the U.S. have issued health advisories regulating fish consumption due to high mercury levels. There are more than 15,000 lakes in Wisconsin, and all of them are covered by an advisory warning people about the level of mercury in the fish caught in those lakes. The Food and Drug Administration (FDA) and the Environmental Protection Agency (EPA) have jointly issued a consumer advisory about mercury in fish and shellfish. They recommend that women who may become pregnant, pregnant women, nursing mothers, and young children not eat shark, swordfish, king mackerel, or tilefish because they contain high levels of mercury, and that they limit fish and shellfish consumption to 12 ounces (2 average meals) a week of a variety of fish and shellfish that are lower in mercury. Five of the most commonly eaten fish that are low in mercury are shrimp, canned light tuna, salmon, pollock, and catfish.

2.2.3 How do people get exposed to Mercury

Air borne mercury is highly toxic when inhaled. Metallic mercury slowly evaporates when exposed to the air. The air in a room can reach unhealthy levels just from the mercury in a broken thermometer. Mercury may be released into the air when coal, oil, or wood are burned as fuel or when mercury-containing wastes are incinerated. The resulting mercury concentrations in outdoor air are usually low and of little direct concern. However, mercury in the air can fall to the ground with rain and snow, landing on soil or in bodies of water, causing contamination. Lakes and rivers are also contaminated when there is a direct discharge of mercury-laden industrial or municipal waste into the water. When mercury enters bodies of water, biological processes. transform it to methylmercury, a highly toxic and bioaccumulative form. Fish can absorb methylmercury from their food and directly from water as it passes over their gills.

2.3 Chemical Properties and Physical Characteristic of Mercury

The chemical and physical characteristics of mercury are shown in Table 2.2 and Table 2.3 respectively.

Table 2.2 Chemical properties of mercury *(http://www.lenntech.com)*

Atomic number	80
Atomic mass	200.59 gmol^{-1}
Density	13.6 gcm^{-3} at 20 ºC
Melting point	-38.9 ºC
Boiling point	356.6 ºC

Table 2.3 Physical Characteristic of Mercury *(http://www.lenntech.com)*

Color	Bright silvery metallic
Luster	Metallic
Transparency	Opaque
Specific Gravity	13.5 (very dense)

2.4 Material Safety Data Sheet (MSDS) of Mercury

MSDS has been prepared according to the hazard criteria of the Controlled Products Regulations (CPR) and the MSDS contains all of the further information about physical and chemical properties of mercury, for further review, see the Appendices.

2.5 Environmental Quality Regulation

Amendment on ENVIRONMENTAL QUALITY ACT 1974 was gazette on 12 October 2009 by the Minister of Natural Resources and the Environment, Datuk Douglas Uggah Embas. The new regulations may be cited as the Environmental Quality (Industrial Effluent) Regulations 2009. With this, the recent Environmental Quality (Industrial Effluent) Regulations, 1979 is annulled. Attached here with the Fifth Schedule and Seventh Schedule of the Regulation.

FIFTH SCHEDULE [Paragraph 11(1)*(A)*]

Acceptable Conditions For Discharge Of

Industrial Effluent Or Mixed Effluent Of Standards A And B

Table 2.4: Industrial Effluent Or Mixed Effluent Of Standards A and B

	Parameter	Unit	Standard	
			A	B
	(1)	(2)	(3)	(4)
i.	Temperature	^oC	40	40
ii.	pH Value	–	6.0-9.0	5.5-9.0
iii.	BOD_5 at 20oC	mg/L	20	50
iv.	Suspended Solids	mg/L	50	100
v.	Mercury	mg/L	0.005	0.05
vi.	Cadmium	mg/L	0.01	0.02
vii.	Chromium, Hexavalent	mg/L	0.05	0.05
viii.	Chromium, Trivalent	mg/L	0.20	1.0

ix.	Arsenic	mg/L	0.05	0.10
x.	Cyanide	mg/L	0.05	0.10
xi.	Lead	mg/L	0.10	0.5
xii.	Copper	mg/L	0.20	1.0
xiii.	Manganese	mg/L	0.20	1.0
xiv.	Nickel	mg/L	0.20	1.0
xv.	Tin	mg/L	0.20	1.0
xvi.	Zinc	mg/L	2.0	2.0
xvii.	Boron	mg/L	1.0	4.0
xviii.	Iron (Fe)	mg/L	1.0	5.0
xix.	Silver	mg/L	0.1	1.0
xx.	Aluminium	mg/L	10	15
xxi.	Selenium	mg/L	0.02	0.5
xxii.	Barium	mg/L	1.0	2.0

Sources: Malaysian Knitting Manufacturers Association

2.6 Mercury in Petrochemical Wastewater

In petrochemical industry, the existing of mercury can give several harmful impacts on the petrochemical processing plant. For examples mercury deposited in cryogenic equipment something caused cracking of welded heat exchangers. Besides that, products used in chemical manufacture, especially olefins, ethylene, aromatics and MTBE, are at risk to mercury in process feeds due to the cited equipment problems and due to catalyst poisoning. The examples of the mercury contaminated treatment system are molecular sieve and glycol dehydration units and amine acid gas removal systems.

Sludge that containing mercury from water treatment systems, separators, reactors and heat exchangers will represents a toxic waste stream that can be difficult to store or processes for disposal as shown in the figure 2.2.

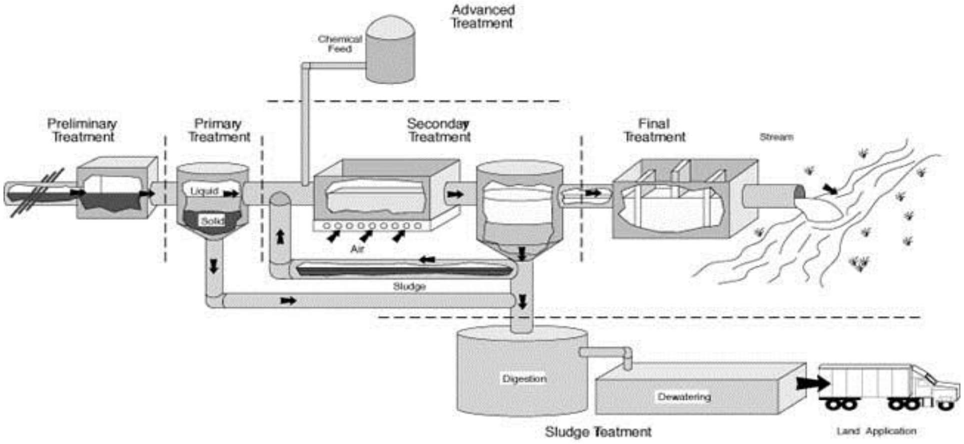


Figure 2.2 Wastewater treatment systems in the petrochemical plant (Hayes *et. al, 1996)*

2.7 Techniques Mercury Removal in Wastewater

Recently there is various techniques to remove mercury from petrochemical wastewater such as membrane process, coagulation process, adsorption on activated carbon, chemical substances and ion exchange through a liquid-liquid membrane. All these techniques are called conventional method for wastewater treatment. As new alternative to improve coagulation process, an electrical element in term of charge is added to the coagulation process and it becomes electrocoagulation process. Electrocoagulation process is more economic and convenient. This process does less harmful impact to the environment without increasing the salinity of the water. Besides that, this method also not expensive.

2.7.1 Membrane Process

Membrane processing is a technique that permits concentration and separation without the use of heat. Particles are separated on the basis of their molecular size and shape with the use of pressure and specially designed semi-permeable membranes. The principle of this process is when a solution and water are separated by a semi-permeable membrane, the water will move into the solution to equilibrate the system. This is known as osmotic pressure**.** If a mechanical force is applied to exceed the osmotic pressure, the water is forced to move down the concentration gradient from low to high concentration. Permeate designates the liquid passing through the membrane, and retentate (concentrate) designates the fraction not passing through the membrane. But there is still a problem which is when these process is continuously run the semi permeable membrane will get stuck by the retentate which also known as the sludge. When the membrane was blocked by the sludge it will reduce the efficiency of this process. Figure 2.3 shows the illustration of membrane processing. (Hayes *el. at, 1996)*

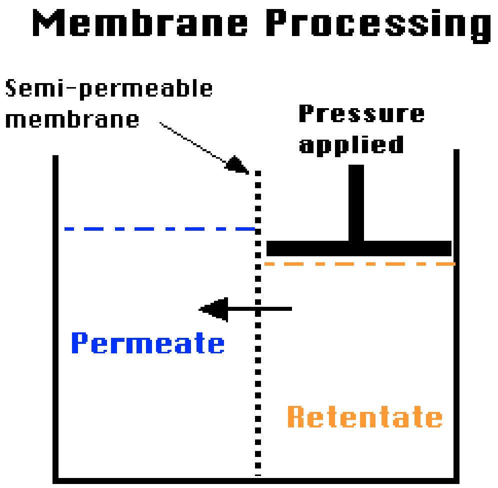


Figure 2.3 Principle of membrane processing (Hayes, *el. at, 1996*)

2.7.2 Chemical Coagulation

In wastewater treatment, coagulation process is widely used. It is also known as flocculation. It is consist of dosing of the coagulant solution to the wastewater in order to reduce the electrical repulsion that caused the combination of the particles. To maintain the electro neutrality in the wastewater charged ion of hydroxyl (OH^-) or hydrogen ions (H^+) are attracted to the pollutant particles oppositely. Table 2.5 shows the coagulant that usually used in the industry.

Table 2.5: Coagulant used in industry (Powell Water System Inc *el at. 1994)*

Chemical Name	**Chemical Formula**
Aluminum sulfate (Alum)	$Al_2(SO_4)_3 \cdot 14\ H_2O$
Ferrous sulfate	$FeSO_4 \cdot 7\ H_2O$
Ferric sulfate	$Fe_2(SO_4)_3 \cdot 9\ H_2O$
Ferric chloride	$FeCl_3 \cdot 6\ H_2O$
Cationic polymer	Various
Calcium hydroxide (Lime)	$Ca(OH)_2$
Calcium oxide (Quicklime)	CaO
Sodium aluminate	$Na_2Al_2O_4$
Bentonite	Clay
Calcium carbonate	$CaCO_3$
Sodium silicate	Na_2SiO_3

There are several disadvantages using chemical coagulation method. During this process, the sludge was increased and contributed high operating cost because the chemical have to supply continuously. (Powell Water System Inc *1994)*

2.8 Electrocoagulation

Electrocoagulation is an electrochemical method of treating polluted water whereby sacrificial anodes corrode to release active coagulant precursors (usually aluminium or iron cations) into solution. Accompanying electrolytic reactions evolve gas (usually as hydrogen bubbles) at the cathode. (Barton *et. al, 2004)*

Electrocoagulation is an effective process for the destabilisation of finely dispersed particles by removing hydrocarbons, greases, suspended solids and even heavy metals from different types of waste water (Inan *et. al, 2004;* Kumar *et. al, 2004;* Chen *et. al, 2002;* Calvo *et. al, 2003;* Saur *et. al, 1996;* Hosny*, et. al, 1996)*. Aluminium or iron usually used as electrodes and their cations are generated by dissolution of sacrificial anodes upon the application of a direct current. The metal ions generated are hydrolysed in the electrochemical cell to produce metal hydroxide ions and only neutral M*(*OH*)*3 has a very low solubility (Duan and Gregory*, 2003)*, mainly at pH values in the range 6.0–7.0 (Pinotti and Zaritzky*, 2001;* Gregor *et al., 1997).* Metal species react with negatively charged particles in the water to form sludge (Chen *et al., 2002;* Saur *et al., 1996)*. The in situ generation of coagulants means that electrocoagulation processes do not require the addition of any chemicals. Figure 2.4 shows example of the operation of the batch electrocoagulation reactor system.

In term of removal mercury electrocoagulation is one of the new efficient way to remove mercury from petrochemical wastewater as it have many advantages if compare will other method *(Powell Water System Inc el at. 1994)*

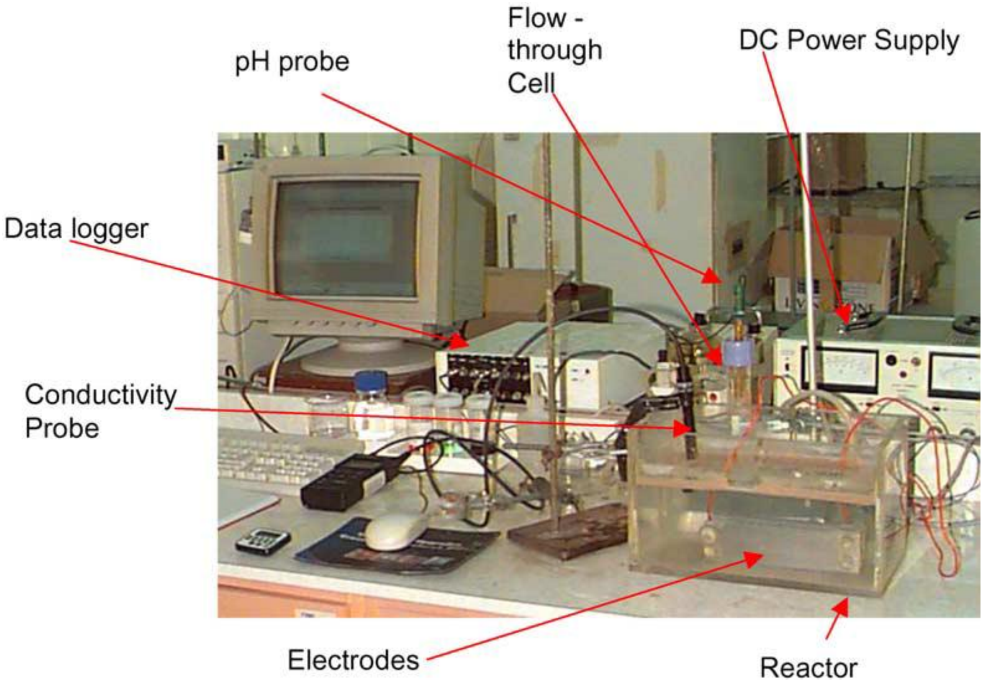


Figure 2.4: Batch electrocoagulation reactor system (Holt *et. al, 2004)*

2.8.1 Advantages of Electrocoagulation

There are many advantages of electrocoagulation process compare to other conventional method especially if compared with chemical coagulation process. Because Electrocoagulation utilizes methods that precipitate out large quantities of contaminants in one operation, the technology is the distinct economic and environmental choice for industrial, commercial and municipal waste treatment. The capital and operating costs are usually significantly less than chemical coagulation. It is not unusual to recover capital costs in less than one year. For the better understanding about the cost of electrocoagulation more cheaper than chemical coagulation this is some example from the industry. For example a 5 GPM system contrasts the advantages of electrocoagulation with a typical chemical coagulation system. This system was designed with the following requirements:

- Reduce Ni from 8.74 to < 3 mg / l
- Reduce Zn from 28.0 to < 3 mg / l
- Reduce TSS from 657 to < 350 mg / l
- Reduce Oil and Grease from 27 to < 15 mg / l
- Reduce Phosphorus from 158.75 to < 10 mg / l
- Process flow rate of 5 GPM (1,500,000 GPY)

The estimated yearly operating cost saving using Electrocoagulation in place of chemical coagulation is $43,500.00 per year. This does not include labor, sludge transportation or disposal costs.

A second example is a system with requirements to:

- Reduce Ni from 25 to < 2.38 mg / l
- Reduce Cr from 210 to < 1.71 mg / l
- Flow rate of 100 GPM (30,000,000 GPY)

Operating cost:	**Chemical Coagulation**	**Electrocoagulation**
per 1,000 gal	$14.18	$1.69
per year	$425,400.00	$50,700.00

The estimated yearly operating cost saving using Electrocoagulation in place of chemical coagulation is $374,700.00 per year. This does not include labor, sludge transportation, or disposal costs. (Powell Water Systems Inc, 1994). From this example we can see clearly that electrocoagulation can save more operation cost compare to chemical coagulation process.

Electrocoagulation also used electricity to precipitate the dissolved and suspended solids. The total dissolved solids in the liquid usually decrease by 27 to 60 percent. This enables the water to be reused in many applications, such as water reuse in steam cleaning operations. Reuse of the water provides a major advantage because this eliminates all EPA and POTW discharge concerns, to say nothing of the replacement costs of the water itself.

Electrocoagulation can produce cleaner water than either chemical precipitation or sedimentation. As discharge requirements become more stringent electrocoagulation will become more essential. Table 2.6 shows the comparison percentage removal between electrocoagulation, chemical coagulation and sedimentation.

Table 2.6: Comparison percentage removal between electrocoagulation, chemical coagulation and sedimentation. *(Sources: Powell Water Systems Inc. 2001).*

	Electrocoagulation	**Chemical Coagulation**	**Sedimentation**
TSS	95 to 99%	80 to 90%	50 to 70%
BOD	50 to 98%	50 to 80%	25 to 40%
Bacteria	95 to 99.999%	80 to 90%	25 to 75%

2.8.2 Arrangement in Electrocoagulation.

Electrocoagulation reactor basically composed of power sources, electrodes, magnetic bar and stirrer. The important parts of the reactor are electrodes which compose of anode and cathode. The reaction will perform on the surface of anode and cathode as there is magnetic forces that stimulate the anion and cation. The electrodes are connected to an external power supply. An electrocoagulation system essentially consists of pairs of conductive metal plates in parallel, which act as monopolar electrodes. It is direct to current power source to regulate the current density and to read the current values.

The electrode are connected to an external power source, the anode material will electrochemically corrode due to oxidation, while the cathode will be subjected to passivation. The electrode can be arranged either in series or parallel. But if the electrodes are arranged in series there a higher potential is required for a given current to flow because the cells connected in series have higher resistance. Other than that if the electrodes are connected in parallel their electric currents are divided between all of the electrodes in relation to the individual resistance of the cell. (Wei *et al. 2007)*

2.8.3 Mechanism in electrocoagulation

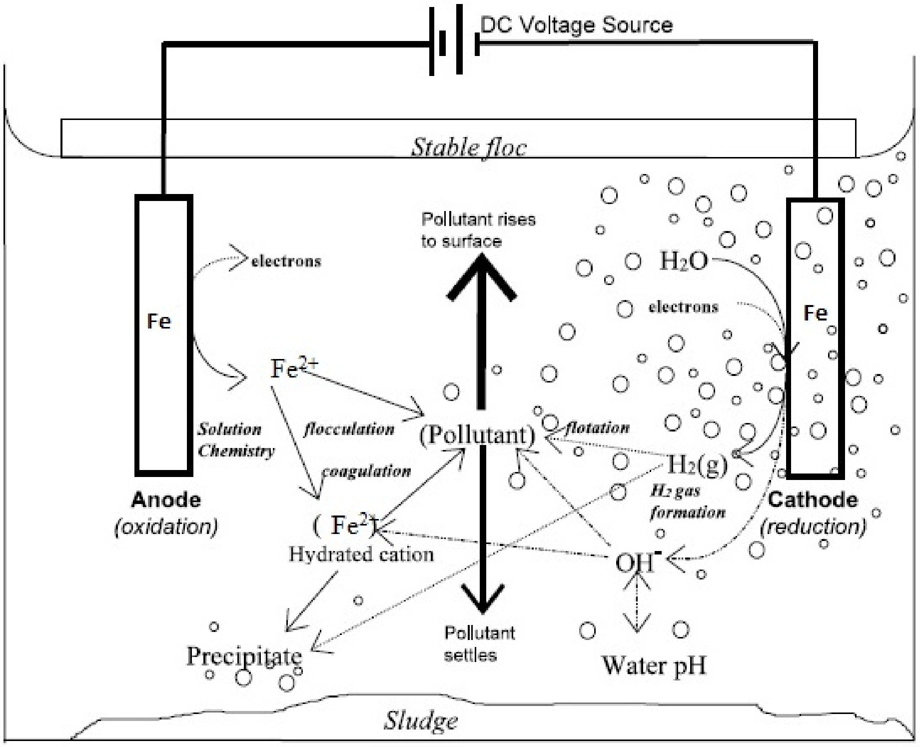


Figure 2.5: Mechanism of electrocoagulation (Holt, *et. al, 2002)*

Figure 2.5 shows the mechanism of electrocoagulation and the reaction occur on this process. It shows the interaction between iron electrodes and the synthetic mercury. Upon treating the solution with iron electrodes, the medium which is green at the beginning of the process becomes progressively yellow. At the end, the filtrate is clear while sludge are also formed. The green and yellow colours result from Fe^{2+} and Fe^{3+} respectively. Fe^{2+} is the common ion generated during the electrolysis of iron, and in the presence of dissolved oxygen in water, it can be easily oxidised into Fe^{3+}. Two mechanisms have been proposed to explain the production of iron hydroxides effect from removal of mercury from petrochemical wastewater

Mechanism 1:

At anode (oxidation)

Equation 2.2: $4Fe \rightarrow 4Fe^{2}+ +8e^{-}$

Equation 2.3: $4Fe^{2}+ +10H_2O + O_2\rightarrow 4Fe(OH)_3 +8H^{+}$

At cathode (reduction)

Equation 2.4: $8H^{+} +8e^{-}\rightarrow 4H_2$

Overall reaction

Equation 2.5: $4Fe + 10H_2O + O_2\rightarrow 4Fe(OH)_3 +4H_2$

Mechanism 2:

At anode (oxidation)

Equation 2.6: $Fe \rightarrow Fe^{2+} +2e^{-}$

Equation 2.7: $Fe^{2+} +2OH^{-}\rightarrow Fe(OH)^{2}$

At cathode (reduction)

Equation 2.8: $2H_2O + 2e^{-}\rightarrow 2OH^{-} +H_2$

Overall reaction

Equation 2.9: $Fe + 2H_2O \rightarrow Fe(OH)_2 +H_2$

During electrolysis, Fe(II) and Fe(III) hydroxides remain in the solution as suspensions and can also remove mercuric ions by complexation or electrostatic attraction followed by coagulation. (Nanseu-Njiki *et. al, 2009 ;* Chen *e.t al, 2000)*

2.9 Electrocoagulation Treatment for Mercury Solution

The treatment was carried out on the solution contaminated by mercury(II) at a certain concentration. The electrodes being iron or aluminium. As a matter of fact, these metals are commonly used in the electrocoagulation processes because they can easily be dissolved and produce metallic cations whose hydroxides are responsible of the coagulation. Moreover, they are not very expensive and do not pose hazard in the environment. (Nanseu-Njiki *et. al, 2009)*

CHAPTER 3

METHODOLOGY

3.1 Introduction

The main purpose of this study is to investigate the effects of parameters on electrocoagulation process in order to remove mercury from the wastewater. The parameters are charge loading, flow rate and the distance between electrodes..

3.2 Experimental Procedures

3.2.1 Experimental apparatus

Experimental apparatus was used for mercury removal in this study is electrocoagulation OT-1 (Figure 3.1). Electrocoagulation OT-1 is installed with two plates of iron electrodes. This electrocoagulation is designed to treat water at maximum of 160 Liters per hour and is comprised of a lid, electrode housing and electrode retaining plate. The concentration of mercury ion before and after treatment were analysed by conductivity meter.

Figure 3.1: Electrocoagulation OT-1 (side view)

Figure 3.2: Electrocoagulation OT-1 (front view)

Figure 3.3: Electrocoagulation OT-1 (back view)

Figure 3.4: Electrocoagulation OT-1 installed with pump and filter

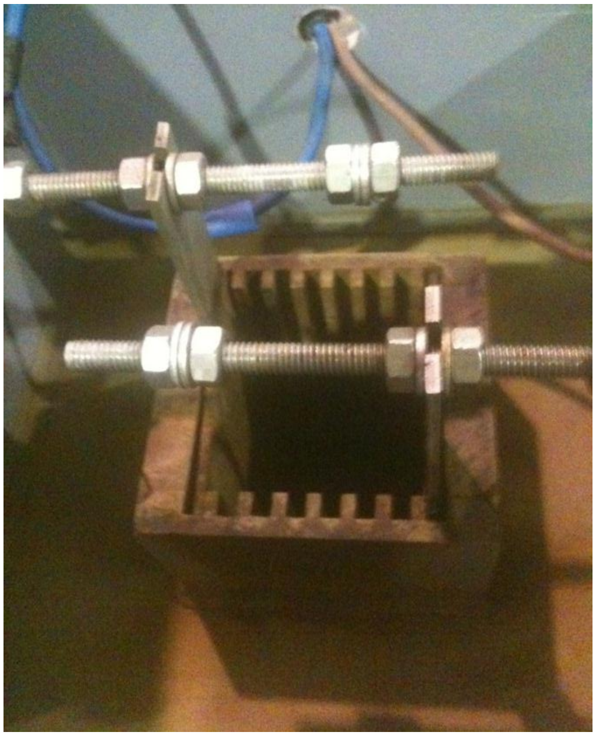


Figure 3.5: Iron plate (electrodes)

3.2.2 Experimental materials

The chemical used are Mercury Chloride 97% purity (Merck), Iron electrode, Sodium hydroxide 37% of purity (Aldrich), Sodium Chloride (Aldrich), Acid Hydrochloric 37% purity (Aldrich) and Acid Sulfuric 90% purity (Merck).

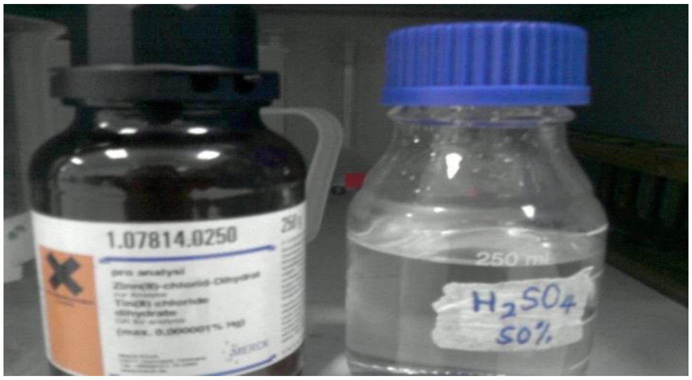


Figure 3.6 Stannum Chloride and Acid Sulfuric

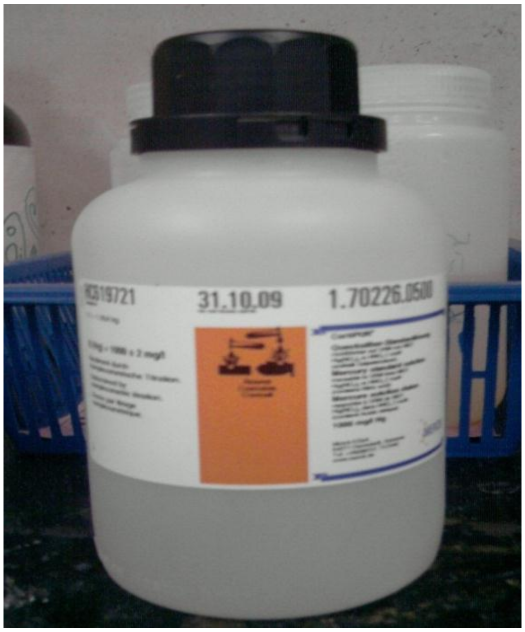


Figure 3.7 Mercury Chloride solution

3.2.3 Procedures Flow of Mercury Treatment

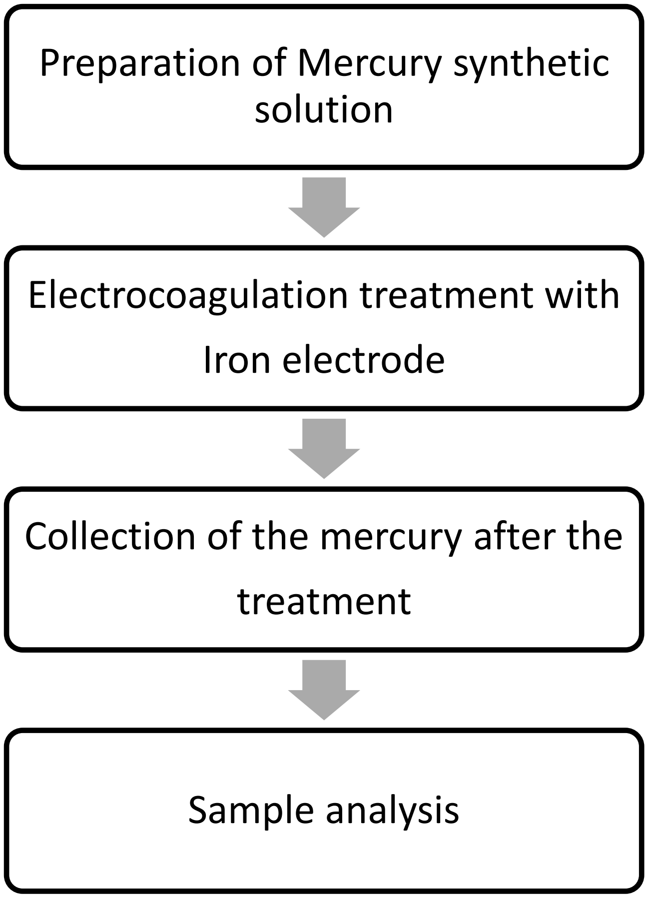


Figure 3.8: Flow of Electrocoagulation process

3.2.4 Preparation of Mercury synthetic Solution

Solutions of mercury synthetic were prepared by dissolving a suitable quantity of Mercury Chloride $HgCl_2$, in deionized water and acidifying it by adding hydrochloric acid (HCl). The pH was adjusted by adding HCl or NaOH, while sodium chloride NaCl, is added to the medium in order to make it conductive.

1000 ppm stock solution of mercury chloride was used to prepare the mercury synthetic. Five different concentrations were prepared for standard solution starting with 0 ppm, 2 ppm, 4 ppm, 6 ppm, 8 ppm and 10 ppm. Since stock solution of mercury chloride is 1000 ppm, a dilution is needed to obtain the standard solution 10 ppm of mercury chloride. Using equation 10:

Equation 3.1: $\boxed{M_1V_1=M_2V_2}$

Then 50 ml from standard solution mercury was diluted in five liters of deionized water in plastic beaker, to avoid a reaction between glass beaker and mercury. Since characteristic of mercury is easily reacting with glass.

Certain amounts of NaCl need to be added into the sample solution, to make it conductive during the treatment. NaCl also will as a catalyst to speed up the reaction Since the NaCl in solid form, dilutions of NaCl need to be performed. Formula of moles and molar is used to dilute the NaCl. 40 gram of 1M of NaCl was diluted in one liters of deionized water. The formula using are:

Equation 3.2: $$Moles(n) = \frac{mass}{molecular\ weight}$$

Equation 3.3: $$Molar(M) = \frac{moles}{volume}$$

3.2.5 Electrocoagulation treatment with Iron electrode

Treatments were carried out using Iron as electrodes. Before each treatment, electrodes are scrubbed with sand paper, then cleaned with 1M H_2SO_4 and rinsed several times with water. The reason is to make sure the iron electrode clean and free from any purity. The electrodes of the same nature separated by a gap were placed parallel to each other in an electrocoagulation OT-1.

Before the electrocoagulation OT-1was turn on, tank and cell electrode in clean and good condition. This is to make sure, it will not affect the sample during the treatment or otherwise the data obtain are not accurate. Firstly sample solution was pour into the tank and followed by adding 100 ml dilutions of NaCl into the sample solution and stirs it together using glass rod. Then, pump was turn on and waits for several minute to make sure the solution was pump through the electrocoagulation cells. Flowrate of the solution can be adjusted using adjust valve. Flowrate of the solution was adjusted from 40 L/h, 80 L/h, 120 L/h and 160 L/h. The charge loading (Ampere) can be obtained by manipulated the voltage regulator. The range of the voltage regulator is from 25v, 50v, 75v, 100v, 125v, 150v, 175v and 200v.

The experiment started with 0 ppm concentration. Flowrate and voltage was manipulated during the treatment. The flowrate, start with 40 L/h and voltage regulation of 25 v, 50 v, 75 v, 100 v, 125 v, 150 v, 175 v and 200 v was recorded. The same step was repeated with different flowrate, 80 L/h, 120 L/h and 160 L/h. From the data comparison, the best flowrate was determined for the next experiment.

The experiment was continued by study the effect of distance between the plates. Distance range of the two plates was varied from 5cm, 4cm and 3cm (figure 3.10). Each distance was investigated based on 2ppm concentration of solution. Two plates were arranged parallel with distance 5cm, 4cm and 3cm, starting with 5cm and then same method was repeated for 4cm and 3cm. Data was obtained by manipulating the voltage regulator.

3.2.6 Sample Analysis

At the end of the treatment the filtrate was collected and analyzed in order to determine the quantity of pollutant eliminated. All the samples were analyzed using conductivity meter to obtain the conductivity of mercury before and after treatment. After that the percentage of mercury removal was calculated.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Result and Discussion

After undergoes several time of experiments and research on electrocoagulation process, I have found that the electrocoagulation process towards mercury can remove until approximately 90% of mercury by using iron as electrode. Therefore certain parameter on effect of flow rate, effect on charge loading and distance between electrodes were investigated.

The efficiency on the elimination of the mercury from the mercury synthetic during the treatment was calculated by its removal efficiency equation:

Equation 4.1: $$Removal\ efficiency\ (\%) = \frac{C_0 - C}{C_0} \times 100\%$$

Where:

-C_0 is conductivity of the mercury before the treatment

-C is conductivity of the mercury after the treatment

4.2 Study the effect on Flow rate

The influence of flow rate (Table 4.1) was examined with the aim to determine the best flow rate. It is important, because the selected flow rate will be constant flow rate for other parameters. Experiment was carried out using water tap supply by JBA Pahang. Untreated tap water may contain unnecessary particles and suitable being treated with electrocoagulation.

Table 4.1: Result on effect of flow rate on electrocoagulation

Flowrate (L/h)	**Voltage (V)**	**Current (A)**
40	0	0
	25	0.05
	50	0.10
	75	0.16
	100	0.19
	125	0.23
80	0	0
	25	0.04
	50	0.09
	75	0.13
	100	0.18
	125	0.22
120	0	0
	25	0.05
	50	0.10
	75	0.14
	100	0.20
	125	0.25

160	0	0
	25	0.04
	50	0.09
	75	0.15
	100	0.20
	125	0.26

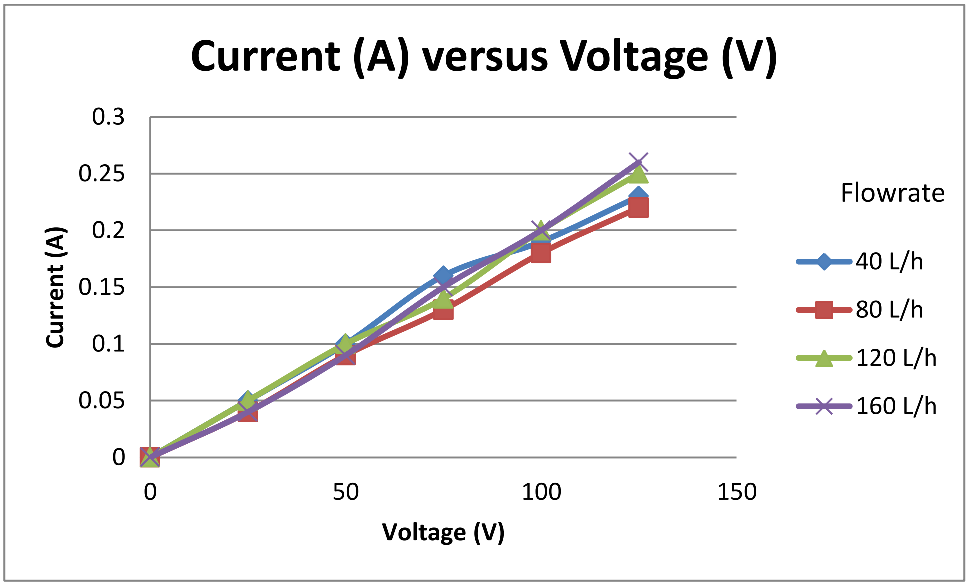


Figure 4.1: Graph of current versus voltage (flow rate)

From the above graph the obtained current (A) was manipulated with voltage regulation for all the flow rate almost show the same result. From the experiment, the higher flow rate will assist the flow of mercury to the plate faster than the lower flow rate. The higher flow rate which is 160 L/h produced higher amount of current which mean the highest efficiency on removal mercury ion. Therefore, higher flow rate which is 160 L/H was used as the basis for other parameters of the studies.

4.3 Study the effect on the charge loading

The experiment was carried out with 10 samples of mercury synthetic which is having five different of concentration, 2ppm, 4ppm, 6ppm, 8ppm and 10ppm. The voltage was manipulated in these studies with the aim to find a range of charge loading values which can be used to obtain the highest removal efficiency. Charge loading is the quantity of electricity per unit volume. From the graph we can see the current (A) which represent as charge loading is increased as the amount of voltages increasing. It shows that the mercury ions were removed from the mercury synthetic solution.

Table 4.2: Result on effect of the charge loading on electrocoagulation

Concentration of samples (ppm)	Voltage (V)	Current (A)
2	0	0
	25	3.20
	50	7.01
	75	8.45
	100	11.88
	125	12.25
	150	13.55
4	0	0
	25	1.70
	50	3.52
	75	6.89
	100	7.24
	125	8.2
	150	8.53

Concentration of samples (ppm)	Voltage (V)	Current (A)
6	0	0
	25	2.23
	50	3.89
	75	7.01
	100	8.68
	125	9.54
	150	10.45
8	0	0
	25	2.27
	50	4.43
	75	7.67
	100	8.55
	125	10.09
	150	10.77
10	0	0
	25	3.45
	50	5.87
	75	6.98
	100	8.76
	125	9.10
	150	9.22

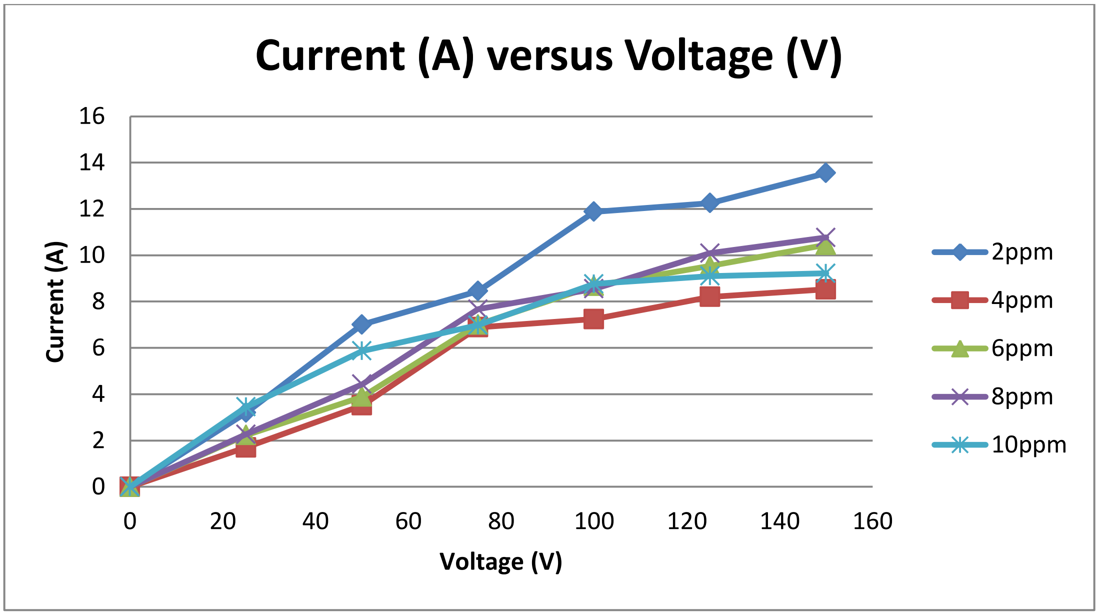


Figure 4.2: Graph of current versus voltage (charge loading)

Table 4.3: Conductivity of sample before and after treatment

Sample concentration (ppm)	Before treatment	After treatment
	Conductivity (μs/cm)	Conductivity (μs/cm)
2	861	85.2
4	899	88.3
6	943	94.8
8	987	97.7
10	1037	103.5

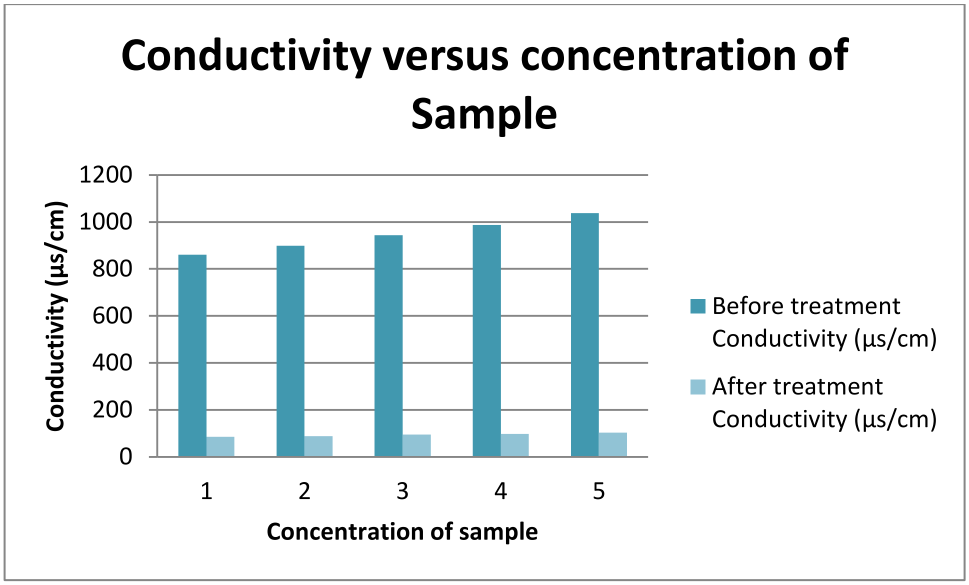


Figure 4.3: Graph of Conductivity versus Concentration of sample

Figure 4.3 show that the conductivity of the sample before and after the treatment by using electrocoagulation process by manipulating the charge loading to see the effect of charge loading toward conductivity of the mercury sample. The conductivity meter was used to check the conductivity of mercury sample before and after the treatment. The efficiency of this treatment was calculated by using equation 4.1:

$$Removal\ efficiency(\%)\frac{C_0 - C}{C_0} \times 100\%$$

C_0 : Conductivity before treatment

C : Conductivity after treatment

Table 4.4: Percentage of mercury removal for mercury sample

Sample concentration (ppm)	Percentage of mercury removal (%)
2	90.10
4	90.08
6	89.95
8	88.93
10	90.02

Table 4.4 shows that, percentage of mercury removal before and after the treatment. From the table, sample of 2ppm having a higher removal mercury which is 90.10% while 10ppm only remove 90.02% of mercury. The data can be conclude the lowest concentration of 2ppm with the highest charge loading contributes to the higher percentage of mercury removal. Result conductivity of mercury that obtain before treatment was not equivalent with the concentration of the sample because before check with conductivity meter the samples need to be dilute it first to get the necessary concentration.

4.4 Study the Effect on Distance between the Electrodes

Table 4.5: Result on the effect on distance between electrodes

Distance (cm)	**Voltage (V)**	**Current (A)**
5	0	0
	25	1.25
	50	5.06
	75	10.1
	100	12.64
	125	13.87
	150	14.3
4	0	0
	25	0.05
	50	5.72
	75	12.88
	100	16.49
	125	17.06
	150	17.91
3	0	0
	25	0.67
	50	4.79
	75	10.39
	100	18.12
	125	20.55
	150	21.6

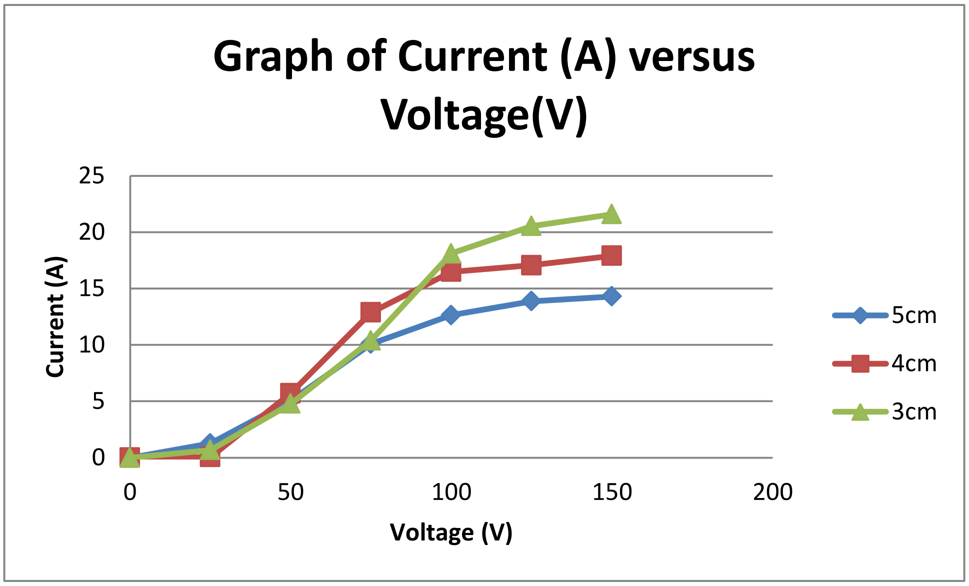


Figure 4.4: Graph of the current versus voltage (distance between electrodes)

For the study of the effect of the distance between two electrode test the distance ranges between two plates were varied at 5cm, 4cm and 3cm using sample with 2ppm concentration of mercury sample. Each distance was studied based on 2ppm concentration of mercury samples. The concentration of the mercury was chosen as the constant variable and the voltage was manipulated variable in these studies to find the optimum distance of the plates that contributes to the highest mercury removal efficiency. From the graph plotting we can determine that 3cm distance between electrodes was most efficient distance that can remove highest percentages of mercury ion. It can be proven as when the voltage increased up to 150V it produce highest amount of current as it is a good indicator for the mercury removal.

Table 4.6: Conductivity of the sample before and after the treatment

Distance between electrode (cm)	Before treatment	After treatment
	Conductivity (µs/cm)	Conductivity (µs/cm)
3	861	99.65
4	861	91.7
5	861	85.2

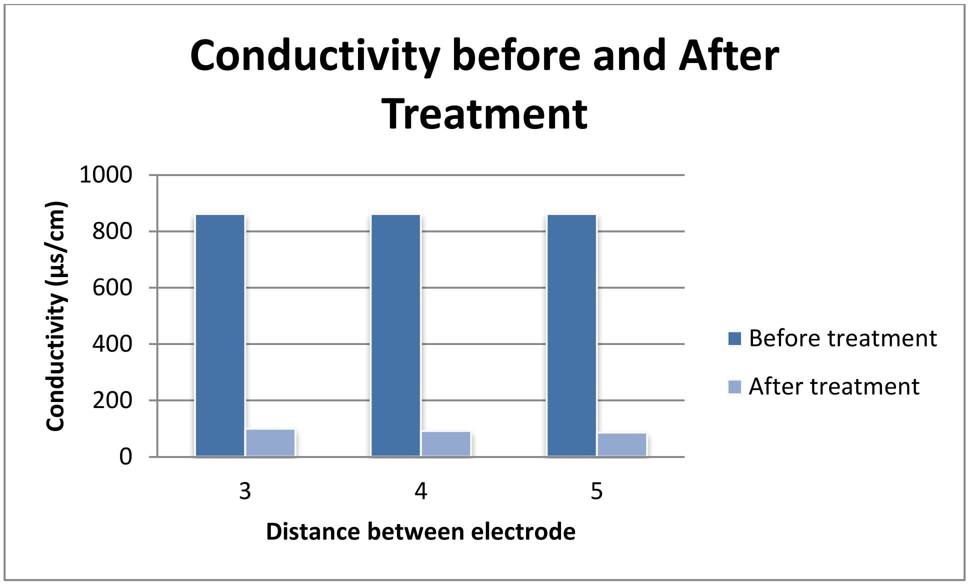


Figure 4.5: Conductivity of mercury before and after the treatment based on the distance between electrodes

In the previous study the effect of the charge loading on the conductivity shows that the sample that having concentration of 2 ppm have the highest and most efficient removal of mercury which is 90.10%. Meanwhile, in figure 2 shows that the conductivity of the mercury before and after the treatment based on the distance between electrodes. We can see that the distances of 5cm between electrodes can remove more mercury ions than 3cm and 4cm distance between the electrodes.

Table 4.7: Percentages of the mercury removal

Distance (cm)	Percentages of Mercury Removal (%)
3	88.43
4	89.35
5	90.10

Table 4.7 shows the percentages of the mercury removal after the treatment. From the table 4.7, 5cm distance between electrodes have highest efficiency of mercury removal which is about 90.10% followed by 3cm distances with percentages of removal of 89.35% and the last distances is 4cm which can remove 88.43% of mercury.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In this research, it was shown that approximately more than 90% mercury successfully removed from the wastewater through electrocoagulation process using iron electrodes. From the experiments the best flow rate for the mercury removal using electrocoagulation process is 160 L/h. For the lowest concentration which is 2ppm with highest charge loading, it contributes to 90.10% of mercury removal. Then for the distance between electrodes 5cm distances bring the best result on mercury removal which is 90.10%.

5.2 Recommendation

Some recommendation can be made to improve the result of the research for the future research:

1. Longer distance from the electrodes can be studied which is more than 5cm
2. It can be more effective if the different time treatment can be investigated even more time required for the research
3. Different type of electrodes other than aluminum can be used for example copper or steel.

LIST OF REFERENCES

[1] Alena Tetreault. Electrocoagulation Process for Wastewater Treatment, Meat & Livestock AustraliaLimited ACN Publishing in February (2003)

[2] B. Mezouk, B Gourich, A. Sekki, K. Madani, M. Chibane. Removal turbidity and separation of heavy metals using electrocoagulation-electroflotation technique, Journal of Hazardous Materials 164 (2009) 215-222

[3] Bassam Al Aji, Yusuf Yavuz, A. Savas Koparal. Electrocoagulation of heavy metals containing model wastewater using monopolar iron electrodes, Separation and Purification Technology 86 (2011) 248-254

[4] C. Noubactep, A. Schoner. Metallic iron for environmental remediation: Learning from electrocoagulation, Journal of Hazardous Materials 175 (2010) 1075-1080

[5] Charles Peguy Nanseu-Njiki, Serge Raoul Tchamango, Philippe Claude Ngom, Andre Darchen, Emmanuel Ngameni. Mercury(II) removal from water by electrocoagulation using aluminium and iron electrodes, Journal of Hazardous Material 168 (2009) 1430-1436

[6] Chantaraporn Phalakornkule, Pisut Sukkasem, Chinnarat Mutchimsattha. Hydrogen recovery from the electrocoagulation treatment of dye-containing wastewater, International Journal of Hydrogen Energy 35 (2010) 10934-10943

[7] Feng Jing-wei, Sun Ya-bing, Zheng Zheng, Zhang Ji-Biao, Li Shu, Tian Yuan-chun. Treatment of tannery wastewater by electrocoagulation, Journal of Environmental Science 19 (2007) 1409-1415

[8] Gholamreza Moussavi, Rasoul Khosravi, Mahdi Farzadkia. Removal of petroleum hydrocarbon from contaminated ground water using an electrocoagulation process: Batch and continuous experiments, Department of Environmental Health Engineering University of Tehran. Desalination 278 (2001) 288-294

[9] Jack Weinberg. An NGO Introduction to Mercury Pollution, International POP's Elimination Network (IPEN) Publishing (2007)

[10] Jewel A.G Gomes, Praveen Daida, Mehmet Kesmez, Michael Weir, Hector Moreno, Jose R. Parga, George Irwin, Hylton McWhinney, Tony Grady, Eric Peterson, David L. Cocke. Arsenic removal by electrocoagulation using combined AL-Fe electrode system and characterization of products, Gill Chair Chemistry and Chemical Engineering, Lamar University. Journal of Hazardous Materials B139 (2007) 220-231

[11] M.F Niam, F. Othman, J.Sohaili, Z. Fauzia. Electrocoagulation technique in enhancing COD and suspended solids removal to improve wastewater quality, Water Science & Technology Vol 56 No 7 pp47-53 IWA Publishing (2007)

[12] Manuel Carmona, Mohamed Khemis, Jean-Pierre Leclerc, Francois Lapicque. A simple model to predict the removal of oil suspensions from water using the electrocoagulation technique, Department of Chemical Engineering, University of Castilla. (2005)

[13] Mark Hyman, MD. The impact of Mercury on Human Health and the Environment, Alternative Therapies, November/December (2004), Volume 10, No 6

[14] Mehmet Kobya, Orhan Taner Can, Mahmut Bayramoglu. Treatment of textile wastewaters by using electrocoagulation using iron an aluminium electrodes, Journal of Hazardous Materials B100 (2003) 163-178

[15] Natural Resources Defense Council, retrieved 20th from http://www.nrdc.org/health/effects/mercury/sources.asp

[16] Peter K. Holt, Geoffrey W. Barton, Cynthia A. Mitchell. The future for electrocoagulation as a localised water treatment technology, Department of Chemical Engineering, University of Sydney, NSW 2006 Australia. Chemosphere 59 (2005) 355-67

[17] Peter Holt, Geoffrey Barton, Cynthia Mitchell. Electrocoagualtion As a Wastewater Treatment, The Third Australian Environmental Engineering Research Event. 23-26 November Castlemaine, Victoria (2006)

[18] Peter K. Holt, Geoffrey W. Barton, Mary Wark, Cynthia A. Mitchell. A quantitative comparison between chemical dosing and electrocoagulation, Colloid and surfaces A: Physicochem. Eng Aspect 211 (2002) 233-248

[19] Ugur Kurt, M. Talha Gonullu, Fatih Ilhan, Kamil Varinca. Treatment of Domestic Wastewater by electrocoagulation in Cell with Fe-Fe Electrodes, Environmental Engineering Science Volume 25, Number 2, (2008) Mary Ann Liebert, Inc.

[20] Woody Hayes Dr., Columbus, Ohio 43210 (1996) Food, Agriculture and biological Engineering, Wastewater Treatment Principles and Regulations, Ohio State University Extension Fact Sheet.