APPLICATION OF ELECTROPHORETIC DEPOSITION IN CAPTURING HEAVY METALSFROMINDUSTRIAL WASTEWATER TOENHANCE HEALTH AND ENVIRONMENT ASPECTS

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THESIS SUBMITTED IN FULFILMENT OF THE REQUIREMENTSFOR THE DEGREE OF MASTER OF SAFETY, HEALTH AND ENVIRONMENTAL ENGINEERING

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APPLICATION OF ELECTROPHORETIC DEPOSITION IN CAPTURING HEAVY METALS FROMINDUSTRIAL WASTEWATER TO ENHANCE HEALTH AND ENVIRONMENT ASPECTS

ABSTRACT

The industrial wastewater pollution is recognized to have a major negative impact on health and environment aspects. It’s mainly contributed by the generation of heavy metals which release to the water body after or during the manufacturing process. In terms of human health, the pollution from heavy metals will lead to serious diseases, while for the environment, the water crises and disturbance of aquatic life are the sequence from the heavy metals pollution. There are various types of water treatments availableto remove heavy metals such as chemical precipitation, ion exchange and membrane filtration. However, these treatments have limitations and weaknesses such as sludge generation, low selectivity, costly and some of them needadditional treatment to improve the removal efficiency.The electrophoretic deposition (EPD) is found to be one of the potential techniques that can be used to minimize these issues.EPD is the process of colloidal particles and regularly carried out in two electrode cells that dispersed in suspension medium with the existence of electric field. To obtain the optimum condition of EPD; the pH, current, particle size of heavy metals, type of electrode, and voltage are determined key factors.This study is to review the EPD process through several points of view, including the process principle, mechanism, effect of parameters and the exploration on EPD studies. A systematic review was used to answer a defined research question by collecting and summarizing all empirical evidence that fits pre-specified eligibility criteria.Additionally, several outlooks based on studies in the literature regarding to health and environmental effects from heavy metals are also presented in this paper.

Keywords: Electrophoretic deposition, heavy metals, industrial wastewater, health, environment

PENGGUNAAN PEMENDAPAN ELECTROPHORETIC BAGI MENANGKAP LOGAM BERAT DI DALAM SISA AIR INDUSTRI SEBAGAI UNTUK MENINGKATKAN ASPEK PERSEKITARAN DAN KESIHATAN

ABSTRAK

Pencemaran air sisa industri diiktiraf mempunyai kesan negatif yang besar terhadap aspek kesihatan dan alam sekitar. Ia disumbangkan terutamanya oleh penjanaan logam berat yang dilepaskan ke badan air selepas atau semasa proses pembuatan di dalam industri. Dari segi kesihatan manusia, pencemaran dari logam berat akan membawa kepada penyakit yang serius, manakala bagi alam sekitar, krisis air dan gangguan kehidupan akuatik adalah urutan dari pencemaran logam berat. Terdapat pelbagai jenis rawatan air yang tersedia untuk menghilangkan logam berat seperti pemendakan kimia, pertukaran ion dan penapisan membran. Walau bagaimanapun, rawatan ini mempunyai batasan dan kelemahan seperti penjanaan enapcemar, selektiviti yang rendah, mahal dan sesetengahnya memerlukan rawatan tambahan untuk meningkatkan kecekapan penyingkiran. Pemendapan electrophoretic (EPD) didapati sebagai salah satu teknik berpotensi yang boleh digunakan untuk meminimumkan isu-isu ini. EPD adalah proses zarah koloid dan secara kerap dijalankan dalam dua sel elektrod yang tersebar dalam medium penggantungan dengan kewujudan medan elektrik. Untuk mendapatkan keadaan optimum EPD; pH, jenis arus elektrik, saiz zarah logam berat, jenis elektrod, dan voltan ditentukan faktor utama. Kajian ini mengkaji semula proses EPD melalui beberapa pandangan, termasuk prinsip proses, mekanisme, kesan parameter dan eksplorasi pada kajian EPD. Kajian sistematik digunakan untuk menjawab soalan penyelidikan yang jelas dengan mengumpulkan dan meringkaskan semua bukti empirikal yang sesuai dengan kriteria kelayakan yang telah ditentukan sebelumnya. Di samping itu, beberapa pandangan berdasarkan kajian dalam kesusasteraan mengenai kesan kesihatan dan alam sekitar dari logam berat juga dibentangkan dalam kajian ini.

Katakunci: Pemendapan electrophoretic, logam berat, air sisa industri, kesihatan, alam sekitar

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LIST OF SYMBOLS AND ABBREVIATIONS

AC	:	Alternating Current
ADMI	:	American Dye Manufacture’s Institute
DC	:	Direct Current
EPD	:	Electophoretic Deposition
FFB	:	Fresh Fruit Branch

CHAPTER 1

INTRODUCTION

1.1 Research Background

Wastewater pollution is a general problem and it still remains a global problem in developed countries. Large amount of freshwater used in daily activities cause the huge amount of wastewater. It is reported that total freshwater withdrawals in the world is about 70% (Liu et al., 2018). Due to rapid growth of population, the industrial sectors will be increased, causing the problem to remain.According to original data from the United Nations Population Division *Population Propects: The 2004 Revision*, the world's population growth in 1950 to 2050 is from more than 2 billion people to 9 billion people.China is the world's largest population country and has been invested in water infrastructure leading to water stressed at many regions(Chao Zhang, 2016). Wang, Shao et al. reported that the wastewater produced in China has greater percentage from the industrial manufacturing compared to agriculture(Wang, Shao, & Westerhoff, 2017).

Among sectors, the industrial wastewater pollution may have major negative impact to environment and human. The environmental impact including extreme weather events, climate change and water crises has consistently featured among the top ranked global risks for the past seven editions of the Global Risks Report(Forum, 2012). The cause of these impact are due tohigh values of classical pollution parameters in terms of chemical oxygen demand (COD), biological oxygen demand (BOD), total suspended solid (TSS), total nitrogen (TN)(Atinkpahoun et al., 2018).Besides, the emission of pollutants from industrial wastewater may lead to illnessesand diseases to human from the exposure to accumulation of chemicals and their derivatives.These diseases can affect the economicdue to sick leaves, reduction of productivity and efficiency of businesses.

Currently, heavy metal contamination has become one of the most serious environmental threats. Because of their high solubility in the aquatic environments, heavy metals can be absorbed by living organisms. Once they enter the food chain, large concentrations of heavy metals may accumulate in the human body. If the metals are ingested beyond the permitted concentration, they can cause serious health disorders (Babel and Kurniawan, 2004). Therefore, it is necessary to purify metal contaminated wastewater prior to its discharge to the environment. Water purification can reduce common contaminates and produce cleaner, safer, better tasting, and better smelling water, better suited for household use. One of the major challenges to the society is to find viable solutions to the growing shortage of clean water. Urgent steps to be taken are: saving water and finding cost-effective methods for treating wastewater, recycling it, and thus increasing the water supply.

Heavy metals in wastewater could be generated from variety of industries including electroplating, semiconductor, battery manufacturing and petroleum refining. The major heavy metals that mainly found in industrial wastewater are cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), iron (Fe), zinc (Zn) and manganese (Mn) (Sörme & Lagerkvist, 2002). These heavy metals basically found in high concentration, therefore the concentrations must be reduced to permissible standards before discharging industrial wastewater into the environment. Beside environment issue, the activity to reduce pollutants also offer the opportunity to improve the economical feasibility of related industry since the deposition of heavy metal can be used further to recover the material needed or gaining interest for economic to be included in the market sectors to other industries. As an example, copper (Cu) is generally found at high concentration in wastewater and it is considered as toxic heavy metals that need to be removed from the water due to its health effects. Furthermore, the captured Cu then also could be utilized for other purposes. According to (Trakal, Šigut, Šillerová, Faturíková, & Komárek, 2014), Cu is widely used in many industrial applications, such as electroplating, metal finishing and plastics.

The efforts of developing the technology to remove heavy metals in wastewater are currently increased. The trend is towards the production of high quality of water as main source of water supplied to meet world’s demand of population, while it expected to improve the standard of living in terms of hygiene and health.Various technologies have been introduced based on the theory and the experimental results which carried out by numerous researchers(Ashutosh Tripathi & Ranjan, 2015; Hani Abu Qdais, 2004; M Nageeb Rashed, 2018; S.F. Mohd Noor, 2016).Several factors must be considered in selecting the technology such as maximum removal level, cost, sustainability (energy saving), and the overall efficiency. Furthermore, the characteristics of heavy metals may also take into accountin selecting the technology to increase the effectiveness.

1.2 Problem Statement

The wastewater treatment process is mainly aimed to remove the heavy metals, organic and inorganic substances, bacteria, pathogens and other chemicals.The captured heavy metal basically is dumped in landfill and incinerator, which consequently can contribute to create the secondary environmental problem. The heavy metals dumped in landfill will be distributed through leachate into the water bodies, while incineration process may produce fly ash to the atmosphere. Kovacs and Szemmelveisz noted that material contaminated with heavy metals are directly discharged due to cost effective(Kovacs & Szemmelveisz, 2017). The ignorance of this issue will cause the increasing volume of wastage and gives the adverse effect for environment as well as human health. This condition occurred due to the conventional process to eliminate heavy metals that has low selectivity in separating the metals.

Heavy metals of industrial wastewater can be removed by using various techniques such as membrane filtration, ion exchange,chemical precipitation, coagulation, and adsorption. Among the technology, membrane filtration and ion exchange are some of the techniques that commonly used to remove heavy metals in industrial wastewater due to high removal efficiency. However, those methods are considered costly since they require more capital and operational cost (S.-Y. Kang, Lee, Moon, & Kim, 2004). Differ with chemical precipitation and coagulation that are characterized as cost effective and high efficiency, but the process may produce an excessive amount of sludge due to high water content from the insoluble heavy metals (Kuan, Lee, & Chern, 2010; Kurniawan, Chan, Lo, & Babel, 2006). Adsorption is the technique with simple design and efficient in industrial wastewater (Demirbas, 2008). The disadvantage of this technique is it produce large amount of hazardous wastes from used absorbent (Kurniawan et al., 2006). In contrast, EPD is considered as cost effective due to its simple apparatus required, short formation of time and easy to control (Besra & Liu, 2007; Boccaccini, 2006).Therefore, the effectiveness of EPD is being studied in this research.According to Besra& Liu, in EPD, the formation of gas bubbles is a general problem occurred during the deposition process. However, this problem can be resolved by manipulating the parameters (Besra & Liu, 2007). Therefore, the optimum conditions need to be investigated from the parameters involved during the EPD process.

1.3 Research Objective

The objectives of this research are as follows:

i. *To investigate the negative effects of industrial heavy metals on human health and environment.*

   All of the major heavy metal wastes that came from the industrial were investigated to get a clear overview of their effect on human health and environment.

ii. *To elaborate the effectiveness of EPD in capturing and removing heavy metals in wastewater*

   The highlight of this study is to investigate the effectiveness of EPD in capturing heavy metals in wastewater and to approach EPD as one of the techniques to be included in the water purification process system. Furthermore, the relevant selection of parameters with optimum condition is also provided to achieve the highest efficiency of EPD process.

1.4 Research Scope

i. Wastewater contains various types of contaminants include organic and inorganic substances, bacteria, chemicals and toxic heavy metals. Therefore, the main focus of this study is to investigate the environment and health effects from heavy metals.

ii. Various types of wastes have been released from wastewater (example solid, liquid, gas) and this research is only focus on heavy metals in wastewater.

iii. As mentioned above, this study is focus on EPD process in capturing heavy metals in wastewater. Basically, there are several applications of EPD, however, only application on heavy metals is reviewed.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Day after day, large amount of hazardous compounds are released from the usage of industries, agriculture, domestic and other human's activities. These activities are play an important role in the wastewater pollution that may have impact to shortage of clean water supplied (Deblonde, Cossu-Leguille, & Hartemann, 2011). Due to high demand of water supplies, beside fresh water, wastewater is also considered as dependablewater source.It can pass on substance and microbial contaminations to urban communities and drinking water admissions found downstream(Wang et al., 2017).

Researchers have found that there is a relationship between wastewater released and human health by spreading the diseases from the river basin to the human body system(Salgot & Folch, 2018). Compounds that are commonly found in wastewater are organic, inorganic pollutants, bacteria, pathogents and toxic heavy metals (Contreras et al., 2017). These compounds will cause illnesses and diseases to human and affect the environment as well. In the last 20 years, new compounds from new products and chemicals with unknown status are found in wastewater by previous researchers withno confirmation on the impact of human health and other living things.This become a challenge to treat wastewater by selecting the most viable and efficient even though various treatments have been introduced (Leonhauser, Pawar, & Birkenbeul, 2014).

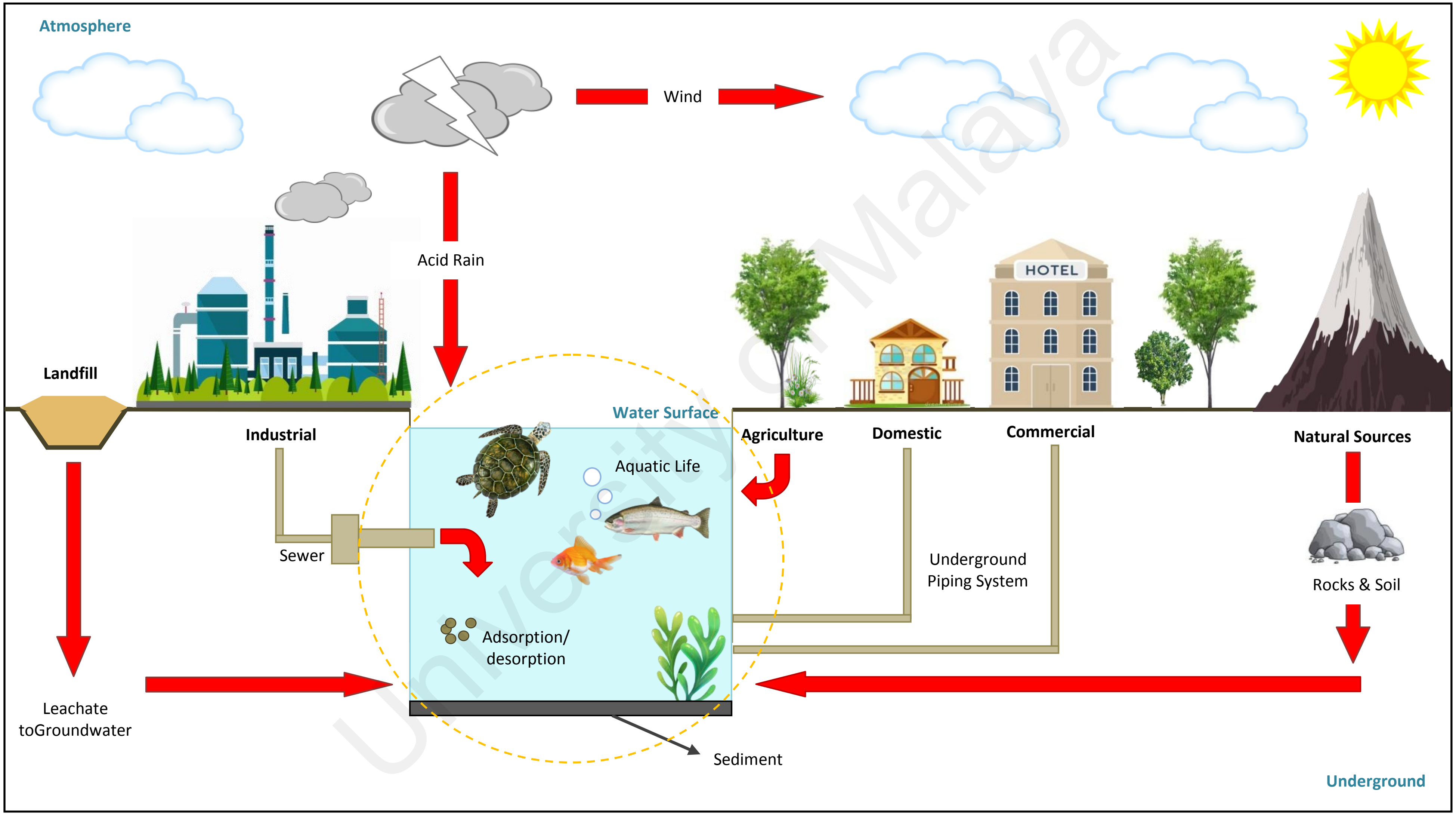


Figure 2.1: Transportation Routes of Waste into WaterSurface

As can be seen from Figure 2.1, waste can be released in many ways into water surface.Basically, waste can be released in natural way through absorbed soil, aquifer rocks and move into the ground water (Edelstein & Ben-Hur, 2018). Sources of wastes in soil include leachate from landfill, sewage sludge, fertilizer from agriculture activities, soil minerals and land treated wastewater (Gupta et. al 2010). In surface water, waste can be carried away in a long distance and its composition and condition varies depending on the geological factors (Kobielska, Howarth, Farha, & Nayak, 2018). Besides releasing through soil and water surface, wastes can be directly or indirectly discharged from various types of industries (Srivastava and Majumder, 2008).Industrial wastewater is found to be the major source of water pollution (Priyanka Lahot, 2016).Due to its different sources, the wastewater may have different types of contaminants and possible to be harmful to human and other living things (Davoudi, Samieirad, Mottaghi, & Safadoost, 2014).

There arevarioustypes of contaminants in wastewater, in which it deals with each one differently. Suspended solids are the particles do not dissolve in water, and can be seen with the naked eye(Giardino et al., 2017). They contribute to the turbidity and can be removed quite easily by using physical or mechanical means such as sedimentation, or filtration(Yahyapour, Golshan, & Ghazali, 2014). Dissolved solid is a measure of total amount of dissolve matter in terms of evaporation. However, this particle cannot be removed easily by using filtration system, but can be reduced by using ion exchange technique(Velvizhi & Venkata Mohan, 2017). Besides, high levels of nutrients and pathogens are released from domestic and commercial waste, and these nutrients are generally nitrogen and phosphorus (Chahal et al., 2016). Differ with biodegradable organics that able to decompose by bacteria to avoid pollution (Simsek, Kasi, Ohm, Murthy, & Khan, 2016). Beside, heavy metals are defined as metallic elements that toxic and poisonous even at low concentrations(Monisha Jaishankar, Tenzin Tseten, Naresh Anbalagan, Blessy B. Mathew , & Beeregowda, 2014). The list of contaminants that commonly found in wastewater along with their sources is given in Table 2.1.

Table 2.1:Type of contaminants in wastewater

Contaminants	Source of Waste
Suspended solids	Domestic/commercial use, industrial wastes
Biodegradable organics	Domestic/commercial and industrial waste
Pathogens	Domestic waste
Nutrients	Domestic and industrial waste
Refractory organics	Industrial waste
Dissolved inorganic solids	Domestic and industrial waste
Heavy metals	Industrial waste, mining

(Howard S.Peavy, 1985)

Among the types of wastewater, domestic and industrial wastewaters are commonly been discussed and studied. Domestic wastewater can be defined as used water from houses including the used water from toilet, washing, bathing and kitchen (Eriksson, Auffarth, Henze, & Ledin, 2002). It is consider as an alternative water source especially for agriculture irrigation and industrial processes (Cui et al., 2017). The untreated domestic wastewater may lead to increase the contamination of bacteria, pathogens, and chemicals which possible to have adverse effect to human and other living things. Differ with industrial wastewater where an aqueous discharge is produced from used water and cleaning activities in manufacturing processes (Samaei, Gato-Trinidad, & Altaee, 2018).

2.2 Sources of wastewater in industrial activities

In industrial activities, the source of wastewater can be obtained from several units in plant: initial unit, process unit and final unitas illustrated in Figure 2.2.The initial unit is pointed to the preliminary stage of the manufacturing process such as cleaning raw materials, preparation, washing equipment, rinsing and cutting process. Followed by process unit that define the stage occur in the primary stage of process of making product, while final unit is the unit where the production is almost done or possible to occur at the end of the overall processes. The wastewaters generated from these units are based on the type of industries and the summary of waste generation for each unit is listed in Table 2.2.

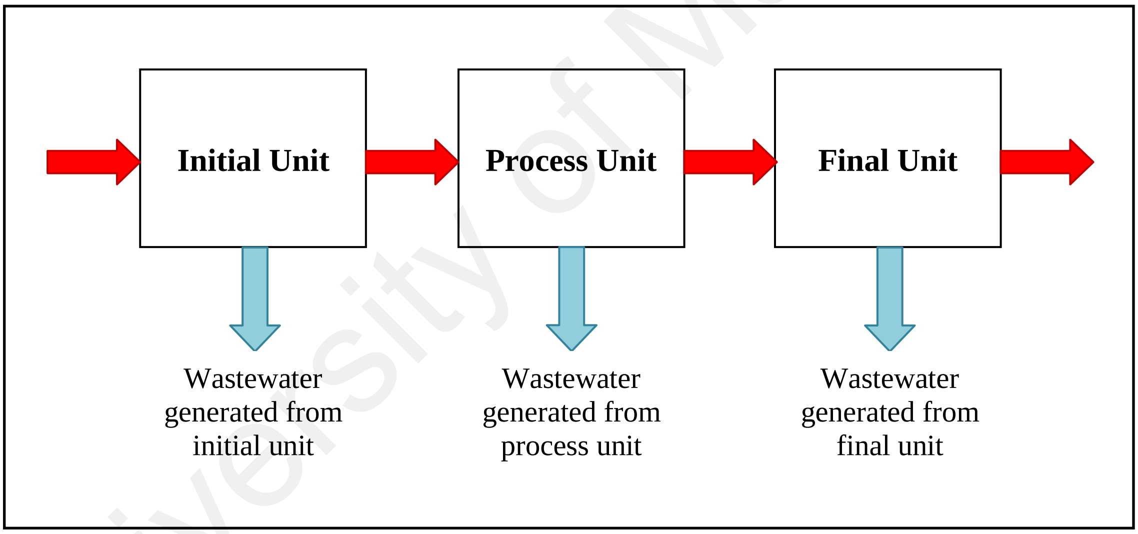
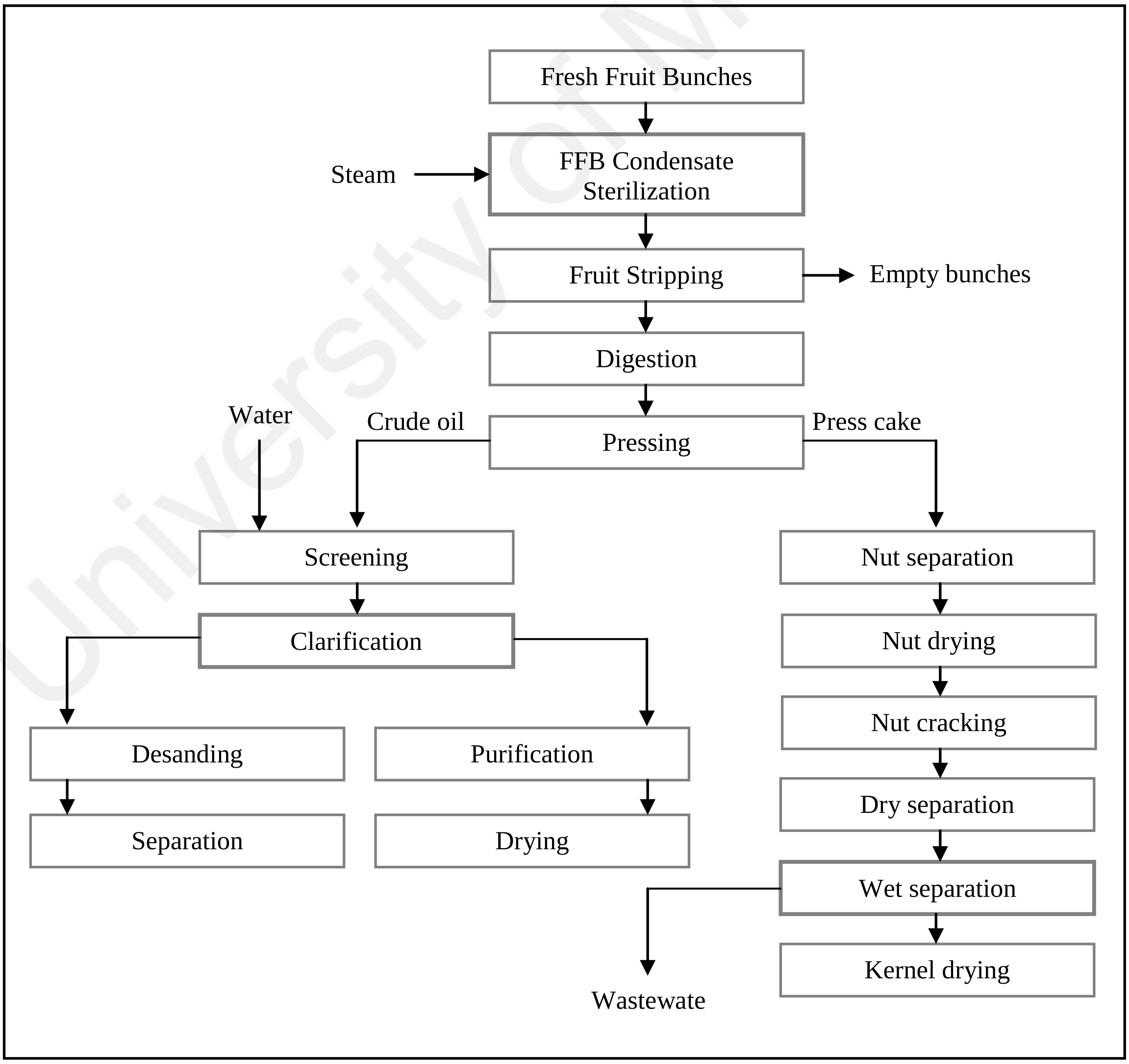


Figure 2.2: **Wastewater generatedfrom the units of manufacturing process**

In palm oil mill industry, the waste discharged from the process is called palm oil mill effluent, also known as POME. Wastewater is discharge from the process of sterilization condensate, nut cracker separation and crude oil clarification. The characteristics of POME is thick concentrated dark brownish colloidal slurry consist of 95% water, 4% oil, 30-70% solid material. The first process involved is sterilized condensate which sterilization is the process where fresh fruit bunches (FFB) is cooked under high pressure. This process is to lose the fruitlet and deactivated the FFB enzyme.

The availability of water content like moisture and water will discharge to sludge pond for POME generation. The second process involve is nut cracker separation. The method used is hydro cyclone to separate and sort particle bin in a liquid suspension andthe process contribute 4% of the total amount of POME. In crude oil clarification, POME is generated from the process of sludge removal through sludge center and desander method to separate oil and sludge. About 60% of water is generated from this process. The location of these processes is illustrated in Figure 2.3below based on the palm oil mill overall process(Abu Bakar et al., 2018; Suwanno et al., 2017; Tan, Poh, & Gouwanda, 2018; Theo et al., 2017; Zainal, Zinatizadeh, Chyuan, Mohd, & Ibrahim, 2018).



.Figure 2.3: Palm oil mill process

Beside palm oil mill, rubber manufacturing industry is also use high level of water during the process. In this industry, there are four main processes that produce wastewater including the process of former cleaning tank, latex dipping tank, leaching tank and latex compounding as shown in Figure 2.4. In former cleaning tank process, the former is cleaned by using acidified, while the waste generated from latex compounding contains water used from the washing of ball mill, latex containers and sludge. Latex dipping is the process where the sludge and used water for cleaning are discharged. After that, the pollutants from the glove will be leached out followed by rinsing it with water. Latex contains about 30% of rubber and the balance is in the form of water in the final stage of wastewater production(Arimoro, 2009; Mokhtar, Lau, Ismail, & Veerasamy, 2015; Nazri et al., 2015; Owamah, Enaboifo, & Izinyon, 2014; Vidanagama & Lokupitiya, 2018).

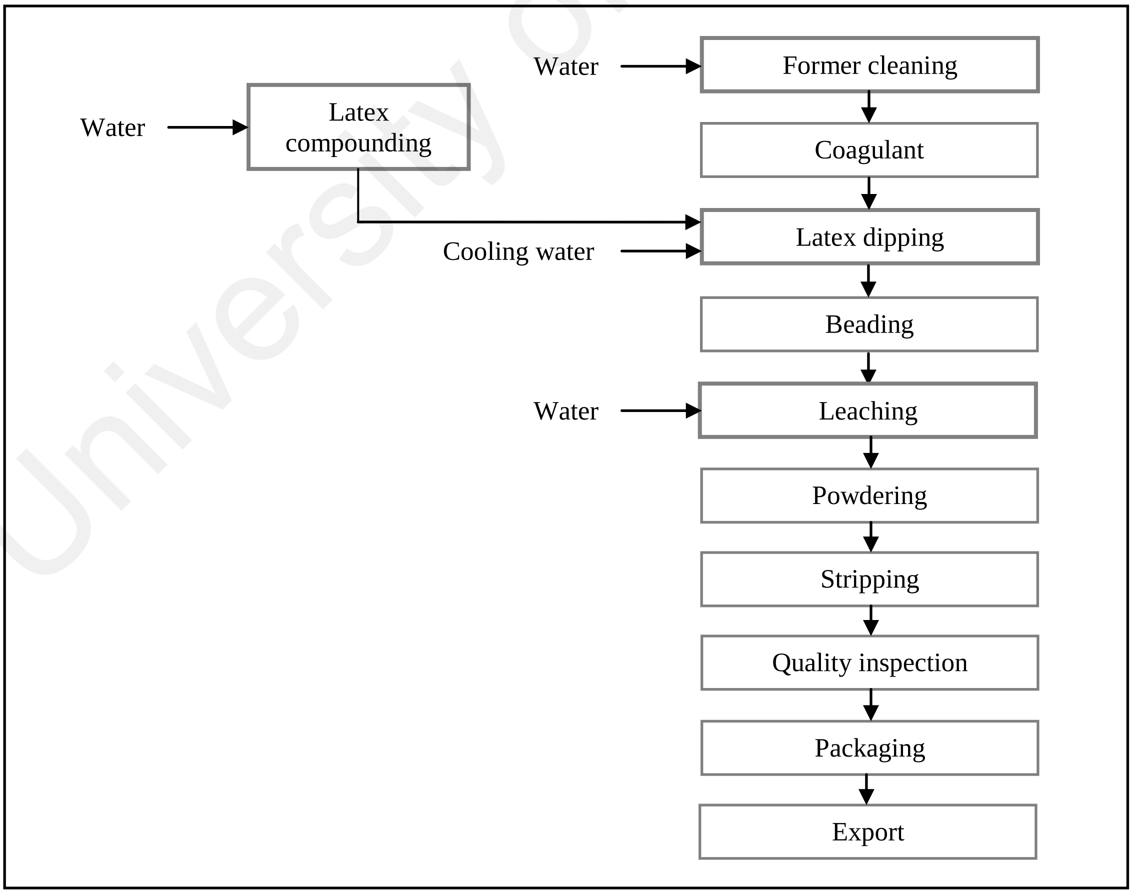


Figure 2.4: Rubber manufacturing process

Figure 2.5 illustrates the process flow of textile manufacturing by using cotton as a raw material. The processbegins with the cotton pre-cleaning through ginning process which separates the cotton fiber from the cotton seeds. Then, cotton yarn is generated by using the process of carding and spinning followed by slashing that wrapthe yarn and protect it from the rigors of weaving. After that, the sizing ingredient in fabric such as starch is removed by in the process of desizing prior to dyeing or printing. This process is to produce the fabric into water soluble product through hydrolysis or oxidation. Generally, about 50% wastewater with high content of BOD is generated from this process. In order to increase the strength of the fabric, mercerizing is the process to improve the quality of the fabric. Lastly, the fabric will be printed and rinsed and the final product is ready. Based on the overall processes, very small amount of wastewater is reported at the process of rinsing, bleaching and mercerizing(Akhtar et al., 2016; Birgani et al., 2016; Costa, Albuquerque, Salgueiro, & Sarubbo, 2018; Mahmoued, 2010; Manai et al., 2016; Swati & Faruqui, 2018).

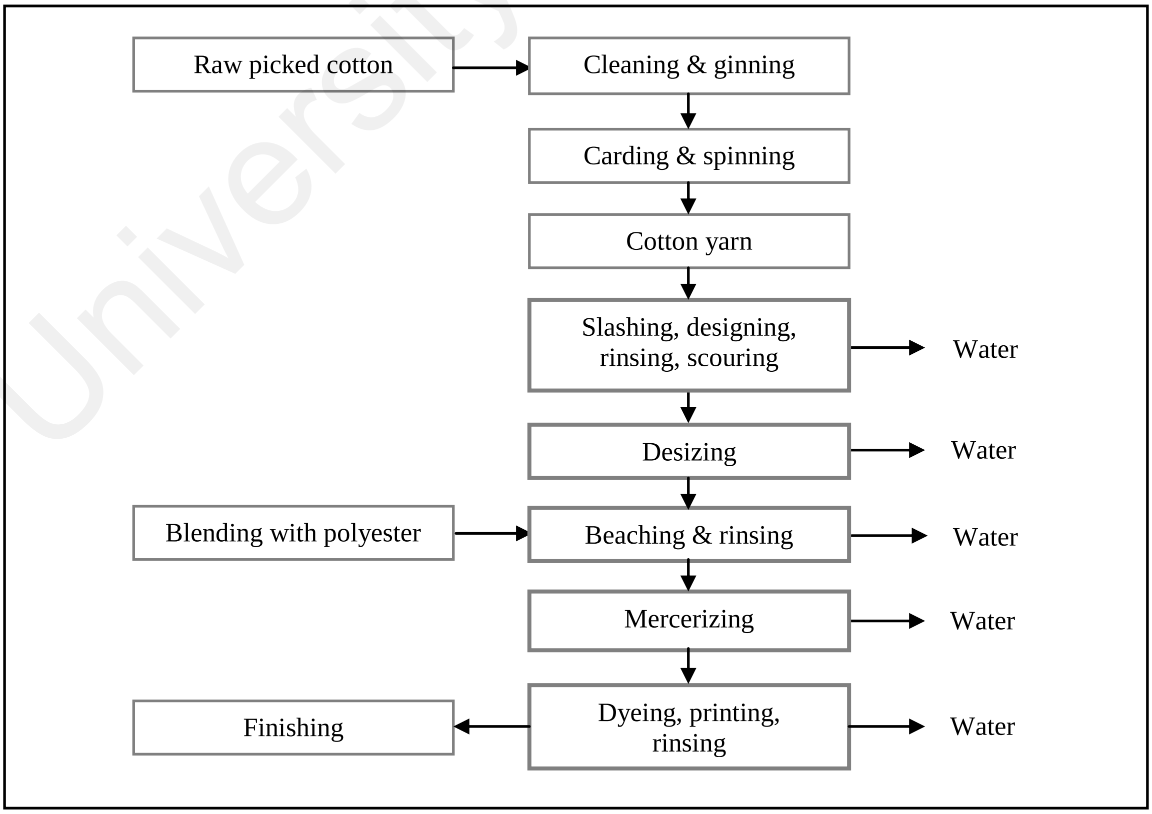


Figure 2.5: Textile manufacturing process

In paper and pulp mill industry, the paper production comes from the trees and the overall process of paper is shown in Figure 2.6.Firstly, the log is fed into a rotating drum to remove the bark and the logs are then chipped. The wood chips are transported to the pulp mill on a conveyer belt. As they enter the pulp mill, the wood chips are fed into a digester where they are cooked by using acid solution to dissolve lignin and separate fibres. The fibres are washed to remove the acid solution and the pulp is now soft and fibrous. Then the pulp is bleached, and any residual lignin, which causes the paper to yellow with age, is filtered. This treated pulp can be dried and transported to paper mill. The pulp is then mixed with the water as stock preparation and followed by the forming process. About 100 liters of fresh water are needed to make one kilogram of paper and about 90% of this water is recycled at the end of process. The delicate paper web is now carried into the pressing which carry away most of the water and drying process using drying cylinders until the paper is produced(Bramhachari, Reddy, & Kotresha, 2016; Budiman, Wu, Ramanan, & Md. Jahim, 2017; Prabakar et al., 2018; Vashi, Iorhemen, & Tay, 2018).

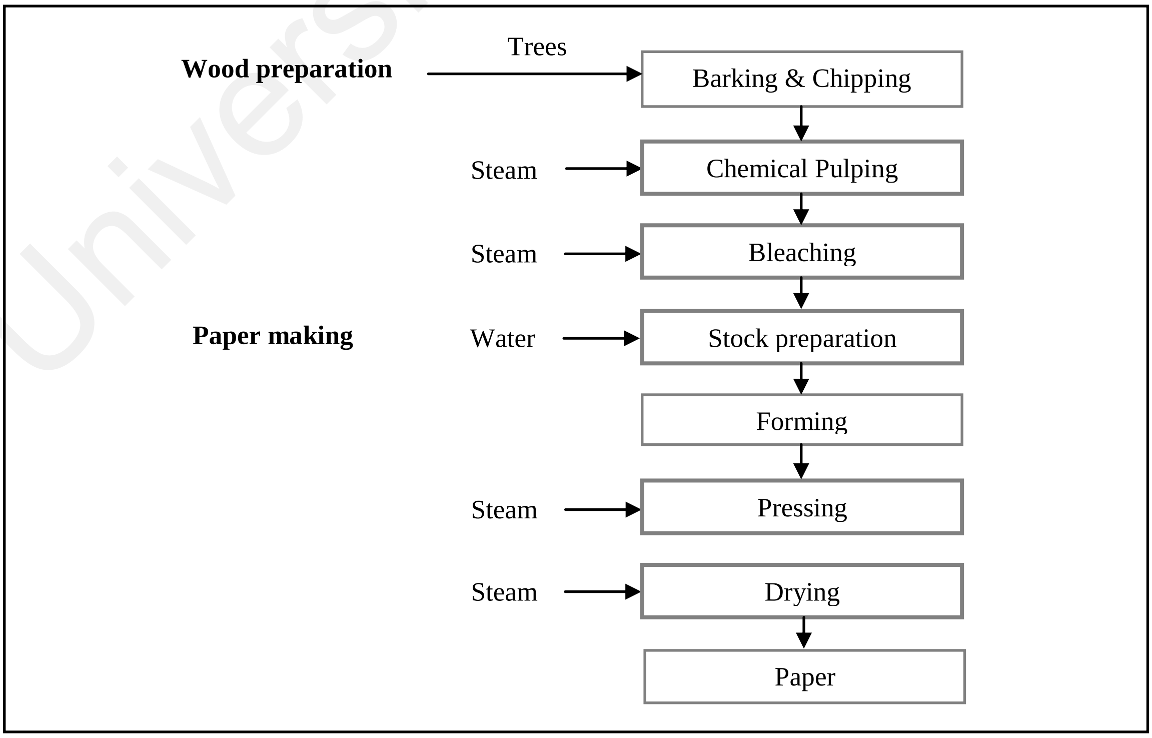


Figure 2.6: Paper and pulp mill process

From the previous explanations on the process of manufacturing in the industrial sectors, it can be concluded that huge amount of water is used almost in every stage of the process. The waste released from those manufacturing processes is summarized in Table 2.2.

Table 2.2: Industrial effluent from the process unit

Unit	Waste Released (%)	Reference
Initial	Small amount, from 4%	(Zainal et al., 2018), (Budiman et al., 2017)
Process	50-60	(Manai et al., 2016), (Birgani et al., 2016), (Zainal et al., 2018)
Final	70-90	(Arimoro, 2009), (Owamah et al., 2014), (Budiman et al., 2017)

2.3 Health and environmental effects from wastewater

The availability of freshwater is depending on the reuse of treated or untreated wastewater (Kumar & Pal, 2018). Reusing wastewater is the common practice in many parts of the world as it generates livelihood opportunity especially in urban city. Wastewater generated from most of industries are discharged into the rivers, lakes, oceans and estuaries (Liu et al., 2018). Some of them are directly discharged from drain system, toilet and etc. without considering the standard limit of wastewater before discharging to the environment and some of them treat it. Direct and indirect counter of wastewater is associated with hazardous substances which frequently gives adverse effect**.**Table 2.3 below explaining the identification of hazardous waste based on the characteristic properties in a liquid or aqueous medium. There are four hazardous waste characteristic properties called ignitability, corrosivity, reactivity and toxicology. Among these properties, most of studies are found that toxicity to be the most concern for hazardous waste in wastewater.

Table 2.3: Hazardous waste identification

Characteristic Properties	Description
Ignitability	Containing less than 24% alcohols (v/v) with a flash point of less than 60˚C
Corrosivity	Aqueous: pH between ≤2.0 or ≥12.5 Liquid: corrodes steel at the rate of greater than 6.35 mm/year
Reactivity	Unstable and react violently with water without detonation
Toxicology	Considering the dynamic processes (absorption, distribution, metabolism, storage and excretion) and route of entry (inhalation, skin, ingestion)

(Barton & Schmitz, 2009)

Wastewater may givenegative impact to environment, and the common activity that can distribute the contamination from wastewater to other medium is through irrigation process (Shakir, Zahraw, & Al-Obaidy, 2017). Irrigation is the process where the certain amount of water is used to help the growth of plant, and to maintain the landscape. The addition of contamination such as chloride (David J. Halliwell, Barlow, & Nash, 2001), substantial salt addition (Fattal, B. Shuval, H.I. Wax, & Y. Davies, 1991) might cause high risk to the land. The impacts include land salinity, land sealing and the increase of run off and land erosion due to sodium accumulation. Furthermore, it can cause soil deterioration and soil permeability reduction, resulting long-term sustainability problems (David J. Halliwell et al., 2001).

Besides the environment, wastewater can also affect to human health resulting the existing of various types of diseases as listed in Table 2.4. There are some cases that have been studied by previous researchers reporting the diseases affected from wastewater generated.

Table 2.4: **Most frequent diseases related to contaminated water supplies**

Type of Diseases	Statistic	Reference
Diarrhea	About 4 billion cases of diarrhea have been reported per year causing 2.2 million death and most of them are children under five years old	(Contreras et al., 2017)
Intestinal Worms	About 10% of world's population in developed countries facing a severity of infection, leading to malnutrition, anemia 10.5 million deaths among children under 5 years In 2008, the percentage of infectious diseases of pneumonia, diarrhea and malaria are 18%, 15% and 8%, respectively.	WHO, 2018 (Benguigui Y & F, 2006) (Black RE et al., 2010)
Trachoma	About 1.3 million people are blind from trachoma, a disease cause by the lack of water combined with poor hygiene practices.	(Resnikoff et al., 2004)
Schistosomiasis	About 240 million people are infected with schistosomiasis with 700 million people worldwide suffer severe consequences.	(Salwa Dawaki et al., 2016)
Cholera	This is a worldwide problem that could be prevented by access to safe drinking water. In 2002, about 0.05% diarrhea cases due to cholera and 11 million cases worldwide reported every year.	(Lanata CF, Mendoza W, & RE, 2002)

Among these,diarrhea is the most frequent affected to human based on cases reported. Other than bacteria, diarrhea can be occurred due to the existence of arsenic in human body system that is basically found in industrialwastewater(Jain & Chandramani, 2018). Therefore, excellent treatment is needed to treat industrial wastewater.

2.4 The importance of wastewater treatment

Harmful substances in wastewater cannot be released to the environment before it is well treated and meet the acceptable permissible standard. There are four main points of why wastewater treatment is important; i) good quality influent water, ii) effluent water quality must meet rules and regulations, iii) save money by recycling wastewater, and iv) recover high value material in wastewater as illustrated in Figure 2.7.The excellent water treatment is important to ensure the treated water can be reused for various activities including for drinking water. Wastewater treatment is fundamental to protect the health of many different ecosystems.Good wastewater treatment allows the maximum amount of water to be reused instead of going to waste.

Figure 2.7: The importance of wastewater

There are many reasons to treat wastewater. Firstly, it is to have good quality of influent water. Many industries require good quality influent water to avoid contamination with the processes and to avoid processes of equipment damages. After water has been used in industry, impurities in the wastewater must be removed and meet the permissible limit before the water is being discharged.Without proper treatment, wastewater may contain high levels of hydrocarbon and chemicals. Many of these substances are toxic, poisonous and even carcinogenic, resulting negative impact to human and environment. There are also situations where wastewater is treated not only to save the environment, but may also to be used by manufacturing processes.This enables the manufacturing plants to conserve water by reusing the treated water. In some countries, where the water resources are scares, many industries are given to look at some way to recycle the wastewater. It is important to recycle wastewater to ensure continuous running of the plant and the reserve capacity. In certain industries, contaminants in the wastewater may have high value of materials such as the gold in wastewater from the gold plating plant, or oil in wastewater from oil refineries. It makes sense to recover these materials as much as possible. If these materials are not recovered from wastewater, high wastage may occur and profitability suffers.

Table 2.5 and 2.6 show the acceptable limit for each contaminant contain in domestic and industrial wastewater before discharging it into the water bodies.The EQA 1974 specifies that Standard A is for the effluent discharged upstream, while Standard B defines as effluent discharged from downstream (EQA 1974). Based on the tables, there is huge difference in types of contaminations between domestic and industrial wastewater. The effluent released from industries contain various types of contaminant and most of them are heavy metals, compared to domestic wastewater that only contain nutrients, oil and suspended solids.This resulted that specific treatment is needed to treat wastewater released from industrial due to high amount of contaminants.

Table 2.5: **Acceptable conditions for discharge of sewage of Standard A and B**

Parameter	**Unit**	**Standard**	
		A	**B**
Temperature	˚C	40	40
pH Value	-	6.0-9.0	5.5-9.0
COD	mg/L	120	200
BOD_5 at 20˚	mg/L	20	50
Suspended Solid	mg/L	50	100
Oil and Grease	mg/L	5.0	10.0
Ammoniacal Nitrogen (enclosed water body)	mg/L	5.0	5.0
Ammoniacal Nitrogen(river)	mg/L	10.0	20.0
Nitrate – Nitrogen(enclosed water body)	mg/L	10.0	10.0
Nitrate – Nitrogen (river)	mg/L	20.0	50.0
Phosphorus (enclosed water body)	mg/L	5.0	10.0

Second Schedule of Environmental Quality (Sewage) Regulations 2009,
Environmental Quality Act 1974

Table 2.6: **Acceptable conditions for discharge of industrial effluent or mixed effluent of Standard A and B**

Parameter	**Unit**	**Standard**	
		A	**B**
Temperature	˚C	40	40
Color	ADMI*	100	200
pH Value	-	6.0-9.0	5.5-9.0
COD	mg/L	50	100
BOD_5 at 20˚	mg/L	20	50
Suspended Solid	mg/L	50	100
Phenol	mg/L	0.001	1.0
Sulphide	mg/L	0.5	0.50
Oil and Grease	mg/L	1.0	10
Formaldehyde	mg/L	1.0	2.0
Free Chlorine	mg/L	1.0	2.0

Table 2.6continued

Parameter	Unit	Standard	
		A	**B**
Ammoniacal Nitrogen	mg/L	10	20
Mercury	mg/L	0.005	0.05
Cadmium	mg/L	0.01	0.02
Chromium, Hexavalent	mg/L	0.05	0.05
Chromium, Trivalent	mg/L	0.20	1.0
Arsenic	mg/L	0.05	0.10
Cyanide	mg/L	0.05	0.10
Lead	mg/L	0.10	0.5
Copper	mg/L	0.20	1.0
Manganese	mg/L	0.20	1.0
Nickel	mg/L	0.20	1.0
Tin	mg/L	0.20	1.0
Zinc	mg/L	2.0	2.0
Iron (Fe)	mg/L	1.0	5.0
Silver	mg/L	0.1	1.0
Aluminum	mg/L	10	15
Selenium	mg/L	0.02	0.5
Fluoride	mg/L	2.0	5.0
Barium	mg/L	1.0	2.0
Boron	mg/L	1.0	4.0

Seventh Schedule of Environmental Quality (Effluent) Regulations 2009,
Environmental Quality Act 1974

Some of country needs to collect water directly from the surface water as drinking water. A water crisis is solvable and there are solutions by new technology and innovation. Therefore, it is important to identify the acceptable limit of effluent and sewage discharge with proper wastewater treatmentto avoid water crises especially water pollution.

2.5 Wastewater and water treatment

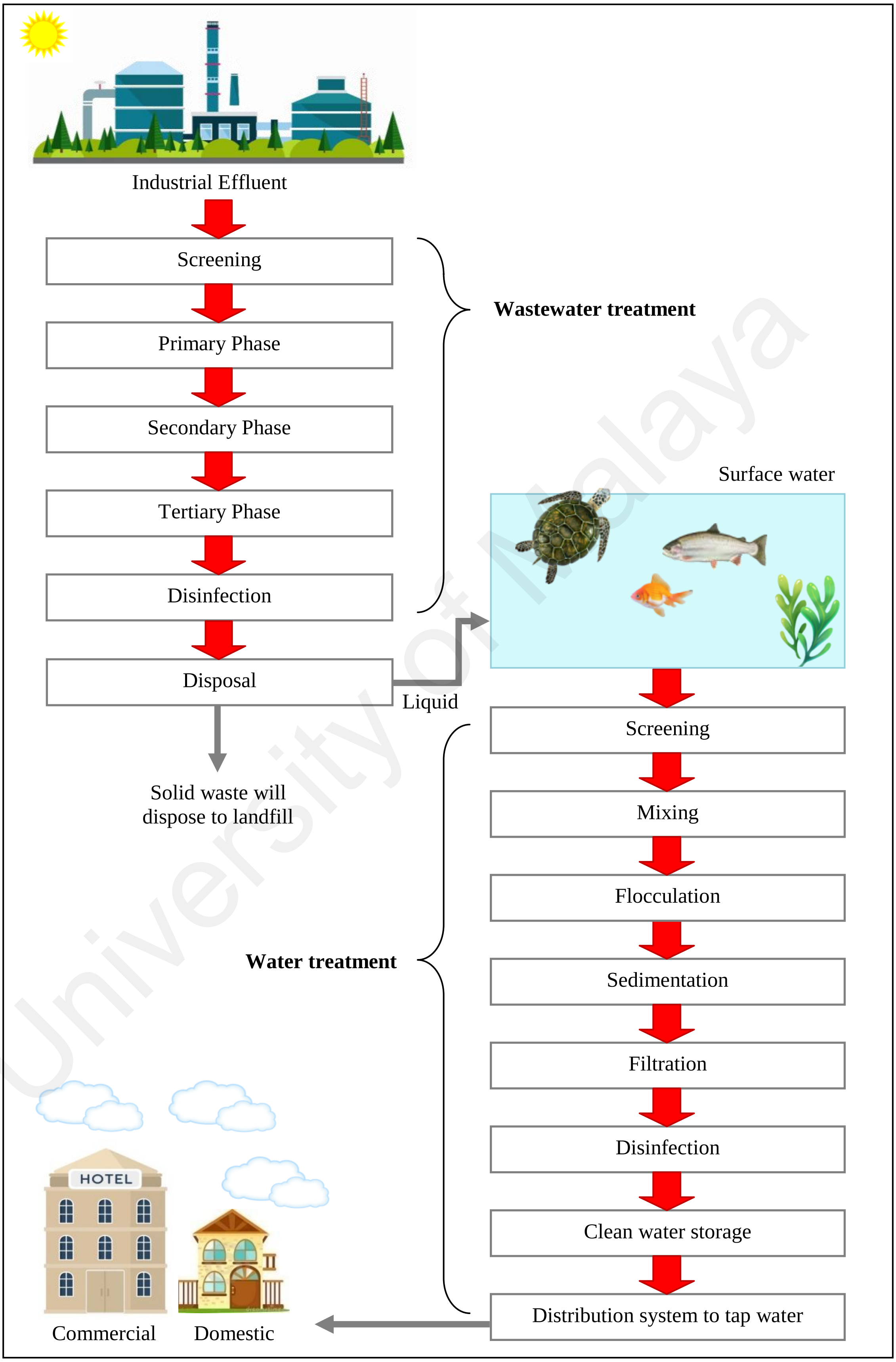


Figure 2.8:The process flow of wastewater and water treatment

It is an interesting idea on how water is get to the tap. Travelling from the water plant to the tap is a long journey. Before the complicated process of treatment to make the water drinkable, it is important to know where the source of the water is.Most of the water source worldwide is from the surface water such as rivers and lakes, or can be groundwater.However, the surface water may have contaminants due to wastewater discharge from industrial activities or also known as industrial effluent. The way of wastewater discharge may be direct or indirect and this is why the water treatment is introduced for further treatment. The tap water will be distributed after go through these treatments.

The primary stage of industrial wastewater treatment is to separate the solid and liquid matter of the sewage. Sedimentation is used asa separation purpose and sewage is kept in large tank designed to carry out sedimentation. This tank is to settle down the sludge at the bottom and oil, grease and other floating materials to rise up to the top. Secondary state is meant to the removal of dissolved biological matter while tertiary stage is a stage is done to improve the quality of water obtained from the secondary stage of treatment. In this stage, various technologies are used to remove various types of contaminants. Water is treated by chemical and physical agent to remove contaminants or any undesirable mass, if present. Then followed by disinfected the waste and it canbe done by chlorination. Then the treated water is ready to be released or disposed to specific place, such as river and lake(De Gisi & Notarnicola, 2017).

After the industrial effluent has been treated in wastewater treatment, there is further treatment for drinking water and it is called surface water treatment. The surface water treatment is generally following the sequence of stages which are screening, mixing, flocculation, sedimentation, filtration and disinfection. These stages are necessary before the clean water is distributed into the distribution system to the water tap. The initial stage is the stage where the coarse floating objects are removed, followed by the addition of oxygen to remove smells, to help the growth of bacteria and to precipitate nuisance metals. Then, the coagulation agent is added to make the particles agglomerate producing sediment at the bottom of the tank, and this sediment is called sludge. Once the sediment is settled out, the upper part of the water is removed and the remaining water is then filtered by filtration system to separate the water and the sludge. The final stage is the process of water improvement by adding oxidation agents such as chlorine, ozone and uv-light. After this process, the water will be stored and ready to distribute through piping system to water tap(Koleva, Styan, & Papageorgiou, 2017).

Both wastewater and water treatmentsareseems like they have the same process but the types of contaminants will differentiate the type of processes involved for each treatment. As discussed earlier, the amount ofcontaminantsin wastewater from industrial sectors are highercompared to the amount of contaminants after the wastewater treatment. Logically, the water discharged after wastewater treatment has lower amount of contaminants. It is because the industrial effluent has been through several treatments by using various technologies based on the type of contaminants. These technologies will be discussed further in the next subchapter and will be only focused on the removal of heavy metals as they are generally found from industrial effluent.

2.6 Heavy metals in industrial wastewater

Heavy metals are refer to any poisonous metal or metalloid with a relatively high atomic mass or density(Fu & Wang, 2011) and are non-biodegradable, which means it cannot be destroyed (Enriqueta Anticó, Sergi Cot, Alexandre Ribó, Ignasi Rodríguez-Roda, & Fontàs, 2017). The elements of heavy metals include arsenic, barium, cadmium, copper, fluoride, iron, lead, manganese, mercury, nickel, selenium, silver and zinc (Prabhu & Prabhu, 2018).Most of heavy metals are toxic and mostly found in industrial effluent including wastewater (Mahurpawar, 2015). These toxic heavy metals can be distributed through the discharge of wastewater into the water bodies, and possible to enter distribution piping system until it reach water tap. The wastewater can be contaminated through industrial activities from various types of industries.Different types of heavy metals are generated from different types of industries as listed in Table 2.7.

Table 2.7: **Heavy metals from industries**

Contaminants	Source of Industry	References
Arsenic	Mining, smelting, dye manufacture, pesticide manufacture, organic and inorganic chemicals manufacture and petroleum refining	(Zhang et al., 2018), (Song et al., 2017)
Barium	Paint and pigment, dye, photocatalyst and ceramic	(Roonasi & Mazinani, 2017)
Cadmium	Mining, refinery,cigarette and chemical industries	(Moscatello et al., 2018)
Copper	Mining, mineral processing, metal-process pickling baths and plating baths, electroplating, chemical manufacturing processes employing copper salts or copper catalyst	(Djouadi Belkada et al., 2018)
Fluorides	Photovoltaic cell manufacture, glass and ceramic manufacture, electroplating, steel and aluminum, pesticides and fertilizer	(Teixeira, Mageste, Dias, Virtuoso, & Siqueira, 2018)
Iron	Mining operations, ore milling, chemical industrial wastewater, dye manufacture, metal processing, textile mills, petroleum refining	(Khatri, Tyagi, & Rawtani, 2017)
Lead	Storage-battery manufacture	(Mukherjee et al., 2018)
Manganese	Steel alloy, dry-cell battery manufacture, chemical manufacture, glass and ceramics, paint and varnish, ink and dye works	(Patil, Chavan, & Oubagaranadin, 2016)

Table 2.7continued

Contaminants	Source of Industry	References
Mercury	Electrical and electronics industry, ore mining, explosive manufacturing, photographic industry, and the pesticide and preservative industry	(Wu et al., 2016), (Attari, Bukhari, Kazemian, & Rohani, 2017)
Nickel	Electroplating, metal-processing industries, steel foundries, motor vehicle, aircraft industries, printing	(Porto, Alvim, & de Almeida Neto, 2017)
Selenium	Paper manufacturing, mining, non-metal smelting	(Staicu, van Hullebusch, Oturan, Ackerson, & Lens, 2015)
Silver	Porcelain, photographic, electroplating, and ink manufacturing	(Jeon, 2015)
Zinc	Steelworks, fiber manufacture, electroplating and metal processing	(Chen, Ren, Li, Trembly, & Liu, 2018), (Babilas & Dydo, 2018)

These toxic heavy metals should be removed from the wastewater, howeverto find the effective and efficienttechnology to remove the heavy metal are still challenging, especially among engineers. As can be seen from the table above, generation of heavy metals in wastewater will be increased day by day from these industries.Therefore, this problem needs to be resolved urgently to avoid before it become worst.

2.7 Technologies for heavy metals removal

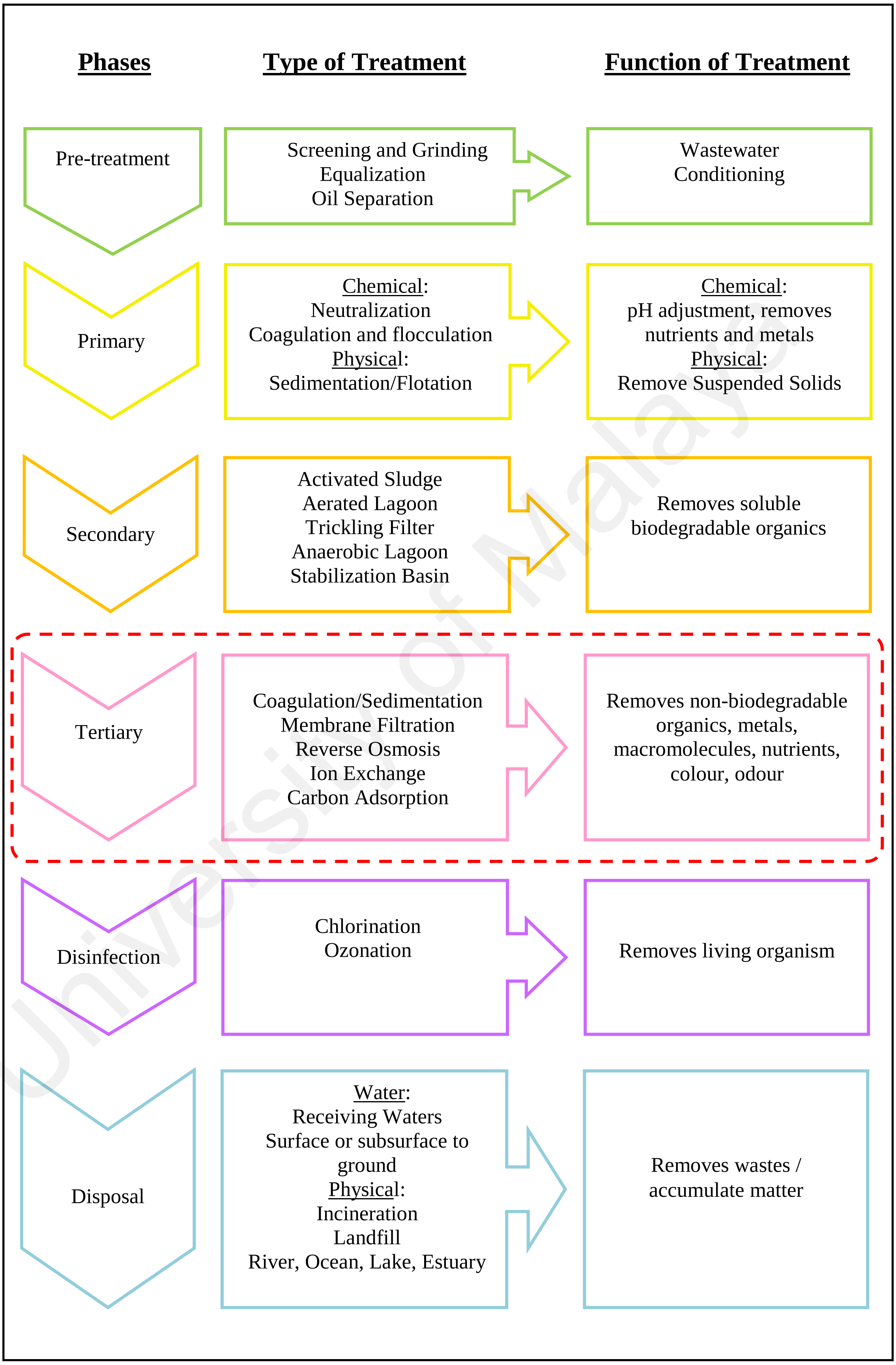


Figure 2.9: Heavy metals removal technologies in wastewater treatment

In wastewater treatment, there are several steps and phases of treatment involved before discharging into the water bodies. However, due to concerning on heavy metals, the main focus is only on the tertiary phase which heavy metals removal techniques are required, as illustrated in Figure 2.9. Currently, numerous techniques of heavy metals removal from wastewater have been introduced and these techniques include chemical precipitation, membrane filtration, ion exchange, and adsorption(Hani Abu Qdais, 2004; Hua et al., 2012; M Nageeb Rashed, 2018; Wan Ngah & Hanafiah, 2008). The advantages and limitations from these technologies are also evaluated.

Chemical precipitation is one of the most common techniques in removing heavy metals due to its cost effective. In this process, chemical agent is added and react with heavy metals ions to produce insoluble precipitates of form. This form develops the separation of heavy metals and water through sedimentation process(Fu & Wang, 2011). According to W.Wesly Eckenfelder 1989, the addition of acidic agent such as lime is generally used during this process to identifythe relationship between the effect of pHand the solubility of heavy metals. However, these heavy metals are able to react with acids and bases and exhibit the point of solubility(Eckenfelder, 1989).Other limitation of this product is the generation of sludge due to sedimentation process and this sludge is then need to be disposed, yet the cost of sludge is high(Kurniawan et al., 2006).

Besides, heavy metals removal can be done by using membrane filtration. This process is capable to remove organic and inorganic waste including suspended solids, and also inorganic contaminants such as heavy metals (Kurniawan et al., 2006).There are three types of membrane filtration process; ultrafiltration, nanofiltration and reverse osmosis. The main function of these processes is to separate water from contaminants(Barakat, 2011). However, all three processes are considered as costly due to membrane filter and for reverse osmosis, high pressure is needed for a separation process. In addition, the membrane used in industrial processes are subjected to fouling and degradation, which limit their applicability in many waste treatment situations(S.-Y. Kang et al., 2004).

In addition to membrane filtration, ion exchange is also one of the processes that commonly relates to heavy metals removal. Ion exchange is the process where the natural solid or synthetic is exchanged its cations with the metals in wastewater. The exchange process occur when the aqueous suspension containing heavy metals passes through the cations column(Fu & Wang, 2011). Even though ion exchange process is convenient due to its portability and has short formation of time, pre-treatment is required prior to this process such as removal of suspended solid and it is not available for all types of heavy metals. Furthermore, secondary pollution will be generated during this process(Ahmed, Chungtai, & Keane, 1998).

Adsorption process is known as effective, economical and eco-friendly process in removing heavy metals(Ashutosh Tripathi & Ranjan, 2015). This process is basically the process of accumulation of surface layer when the solid surface is in contact with a solution due to unbalanced surface forces, chemically and physically(Eckenfelder, 1989). Chemical adsorption is the adsorption process from the chemical reaction while physical adsorption is using van der Waals forces to bind adsorbate and adsorbent (Kaveeshwar et al., 2018). Activated carbon and carbon nanotube are commonly used as adsorbent to removed heavy metals during the process(Demirbas, 2008). In recent years, the adsorbent has been change to low cost materials due to high cost of activated carbon. However, this process has low selectivity due to its low efficiency in removing heavy metals in water (Babel & Kurniawan, 2003).

As discussed above, these processes have their own advantages in terms of cost, efficiency, and the duration of time during the process. However, there are also limitations for each technique. The limitations for the heavy metals removal techniques are summarized in Table 2.8.

Table 2.8: The main disadvantages of heavy metals removal techniques

Heavy Metals Removal Techniques	Disadvantages	References
Chemical precipitation	Sludge will be generated, high cost for sludge disposal	(Kurniawan et al., 2006)
Membrane filtration	High cost due to membrane filter	(S.-Y. Kang et al., 2004)
Ion Exchange	Additional treatments are required, not available for all heavy metals, secondary pollution will be generated	(Ahmed et al., 1998)
Adsorption	Low selectivity	(Babel & Kurniawan, 2003)

CHAPTER 3

METHODOLOGY

3.1 Review method selection

This study is considered as a review study. There are three main types of reviewswhich are critical review, narrative review and systematic review. The critical review is the critical evaluation, identification and summarization of an article.The results from critical review are normally in hypothesis and model type. It is basically one to four pages in length that summarize only the critical part of the study.Besides, continuing from the previous studies is called narrative review. This type of review is for up-to-date purposes about specific topic that has been studied before. However, narrative review has no methodology involved and no list of database is required(Green, Johnson, & Adams, 2006).Differ with systematic review that is defined as well planned reviewto answer specific research question.The purpose of data collection is as research support to produce best practiceof research.This review is considered as the original work due to rigorous methodology approach(Aromataris & Pearson, 2014).

In this study, systematic review is selected due its criteria that meet the requirement of this review. The approach use of this methodology is referring to systematicreview, where to conduct this methodology, the main seven steps are recommended based on the Cochrane Handbook of Systematic Reviews of Interventions. The seven basic steps include posing research question, locating studies, critical evaluation of studies, data collection, data analysis, reporting, and interpretation of findings. Figure 3.1 below illustrates the overall process flow systematic review which consist of all seven basic steps as recommended.

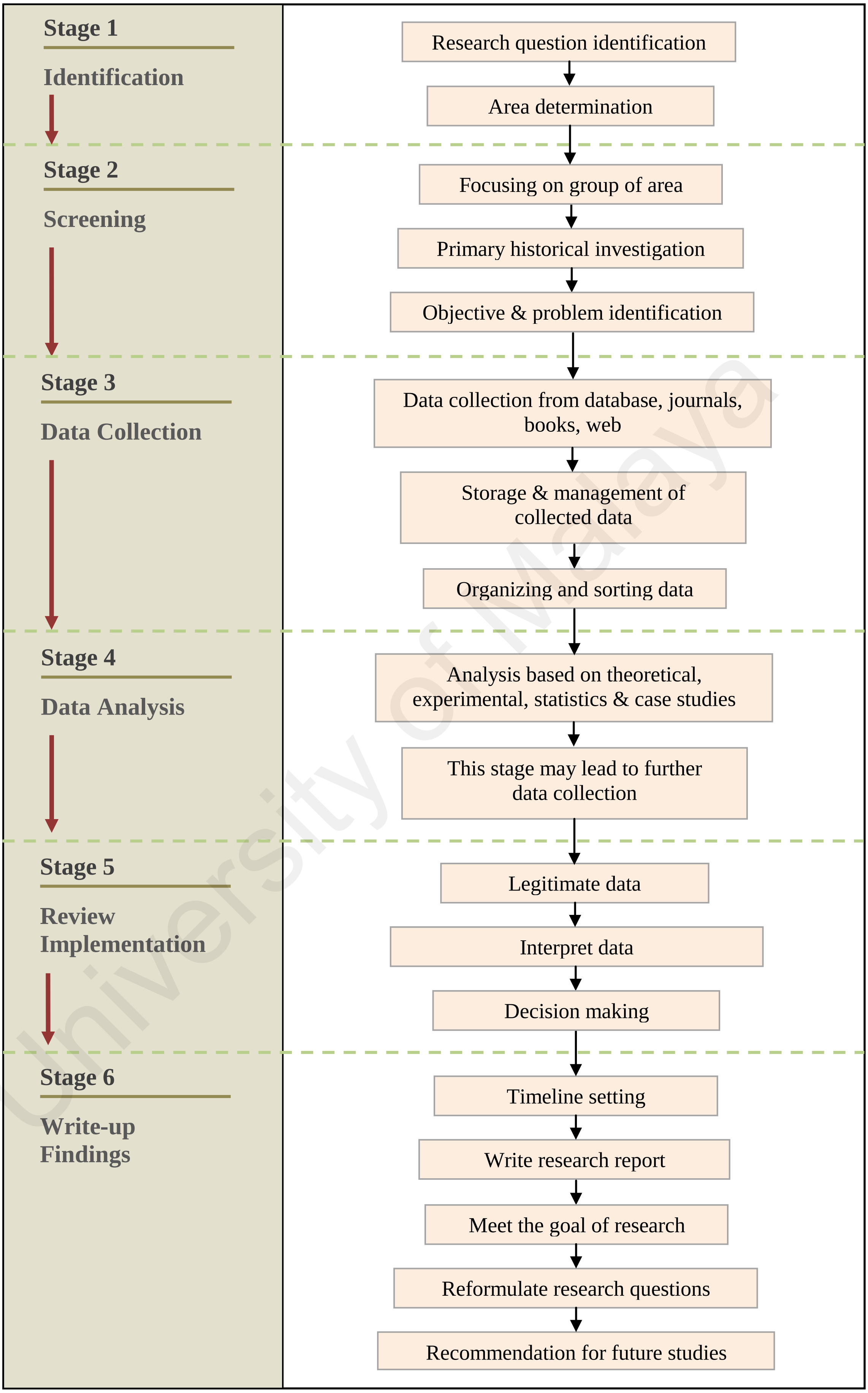


Figure 3.1: Review Process Flow

3.2 Review process flow

Based on Figure 3.1, there are six stages involved in this review process flow. The six stages consist of identification, screening, data collection, data analysis, review implementation and write up findings. The initial part is called identification where the preliminary investigation is done based on the approved title. In this part, the basic idea of what the research is all about with related field is identified.

Then, the area of research is narrowed down to the focused group. The primary search is investigated by searching of data based on the nature of study. This study reviews several aspects which include principle, mechanism of EPD and parameters involved in the process. Then, the EPD process to capture heavy metals from industrial wastewater and the effectiveness of EPD is also presented in this review. Prior discussing on EPD, the health and environment effects from heavy metals are also been discussed.The relevant trials of search strategies are identified by using various terms and synonyms include “heavy metals”, “metal nanoparticles”, “EPD”, “electrodeposition”, and “electrocoating”.

After that, the related data is collected and it is define as the most important part of this research. Data collection is the process of preparing and describing the source of research. Lack of research and inaccurate data collection may affect the overall results of research due to invalid result. Stage four is data analysis and the analysis is based on the theoretical, experimental, statistics and case studies. It is important to analyze data because this process may lead to further data collection. The results studied by previous researchers are valuable and from here, the information of what was happened can be collected. This useful information is stand only as supporter to this research without any plagiarism involved.

The process is followed by research implementation through data interpretation. This process is the process where all collected data is interpreted based on previous studies and also includes law and regulations. The more the evidence, the more quality of research will be produced. Finally, the process is end by writing up this research report. The outcome of this study includes the estimation of the best parameters to be considered for excellent result of EPD. The relationship between the particles size, type of suspension, applied voltage and current of electric and other relating parameters may take into account. Besides, it is to prove that EPD is the process which cost effective, simple and efficient in capturing heavy metals in aqueous suspension.

3.3 Data Collection

Data collection is the crucial part for this review. There are various ways to collect data and it is basically collected through the following ways:

3.3.1 Year of Publication

The total references are 141 and about 90% of these references are collected from journals. The collection of data is collected from 1985 to updated year of publicationand the lists are summarized as follows:

Table 3.1: No. of reference based on year of publication

Year	No. of references	Year	No. of references
2018	31	2010	8
2017	22	2009	8
2016	16	2008	4
2015	7	2007	2
2014	8	2006	4
2013	1	2005	1
2012	5	2004	4
2011	4	2003	1

Table 3.1 continued

Year	No. of references	Year	No. of references
2002	3	1996	2
2001	2	1991	1
1999	1	1990	1
1998	1	1989	1
1997	1	1985	1

3.3.2 Work Schedule

This study was performed from February to July 2018 at University of Malaya. The study is started from the approval of title until the final presentation as summarized below:

Activity	2018						
	Feb	Mar	Apr	May	Jun	Jul	Aug
General discussion on proposed topic with supervisor and confirmation of title	■						
Approval of title and appointment of supervisor by faculty		■					
Preparation of table of content for the overall review, selectivity of objective and problem statement identification		■					
Preparation of Chapter 1 (Introduction)		■	■				
Preparation of Chapter 2 (Literature Review)			■	■			
Preparation of Chapter 3 (Methodology)				■			
Preparation of Chapter 4 (Results and Discussions)				■	■	■	
Preparation of Chapter 5 (Conclusion)						■	
Final presentation (Viva) as informed by faculty through email							■

Figure 3.2: Gantt Chart

3.3.3 Online Publishing Site Database

The online publishing sitesdatabases for data collection are as follows:

i. ScienceDirect

ii. ScienceDirect e-Books

iii. Wiley Online Library (2012-2015)

iv. Wiley e-Books

v. Scopus

vi. SpringerLink

3.3.4 Registered Electronic Journals

The registered electronic journals for data collection are as follows:

i. Journal of Cleaner Production

ii. Journal of Bioremediation & Biodegradation

iii. Journal of Environmental Chemical Engineering

iv. Journal of Hazardous Materials

v. Arabian Journal of Chemistry

vi. Journal of the European Ceramic Society

vii. Journal of Environmental Management

viii. Journal of Colloid and Interface Science

ix. Chemical Engineering Journal

x. Journal of the European Ceramic Society

xi. Journal of Environmental Sciences

xii. Journal of Natural Gas Science and Engineering

xiii. International Journal of Hygiene and Environmental Health

xiv. Journal of Hazardous Materials

xv. Indian Journal of Medical Specialities

xvi. Journal of Industrial and Engineering Chemistry

xvii. Journal of Alloys and Compounds

xviii. Journal of Cleaner Production

xix. Journal of Water Process Engineering

xx. Journal of Materials Science

xxi. International Journal of Research-Granthaalayah

xxii. Journal of Water Process Engineering

xxiii. Journal of Research in Science, Technology, Engineering and Management (JoRSTEM)

xxiv. International Journal of Science, Research & Sustainability

xxv. Journal of Environmental Chemical Engineering

xxvi. Journal of Advanced Review on Scientific Research

xxvii. Journal of Colloid and Interface Science

xxviii. Egyptian Journal of Petroleum

xxix. Journal of Chemistry

xxx. International Journal of Hydrogen Energy

xxxi. Journal of Water Resource

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Health Effectsfrom Heavy Metals

Heavy metals have their own advantage in living microorganism at low concentration. However, it becomes harmful when the concentration exceeded the acceptable limit. It is proven that the toxicity of heavy metals is considered as major threat with several health risk associated with it(Monisha Jaishankar et al., 2014).Heavy metals can be absorbed easilyand remain in human body and other living things due to high in solubility(Kurniawan et al., 2006).

	
Drinking water from water tap	**Direct contact from daily activities**

Figure 4.1: The health effects from daily activities

There are two ways on how heavy metals affected to human body, through direct contact with the water containing heavy metals and through drinking water as illustrated in Figure 4.1.Direct contact is generally affecting the skin and eye from daily activities such as bathing and washing clothes by using water from the river or lakes. Differ with drinking water, the heavy metals can enter and absorb into the body system. After the compound is absorbed, it travels through vascular system such as blood stream, where it moves through the body and attached to targeted organs. The organs that are possible to have toxic effects due to the attachment are lung,kidney, liver and blood itself. The storage may or may not occur, depending on the partition behaviour between contaminants and biomolecules.The metals that are highly water soluble and no possibility to partition are rapidly eliminated in the urine (H. Y. Kang et al., 2017).

Either through direct contact or drinking water, the effect from heavy metals is based on the health characteristics, as listed in Table 4.1. These characteristics explaining on how does health effect occurs.

Table 4.1: **Health affects characteristics**

Health Effects Characteristic	Description
Acute & chronic effects	Acute: short period of exposure with high concentration, resulting immediate effects Chronic: long-term effects due to repeated or long duration of exposure with low concentration
Local & systemic effects	Local: first contact with the chemical, such as on corrosive chemicals that immediately effect the skin Systemic: when the chemical absorb into the body from initial point of contact
Immediate & delayed effects	Immediate: effect develop soon after exposure Delayed: after some times of exposure

Table 4.1continued

Health Effects Characteristic	Description
Target organs	Organ or tissue where adverse effects occurs
Reversible & irreversible effects	Reversible: occur after end of exposure Irreversible: occur after end of exposure, and may even progress
Other specific effects	Carcinogenicity, mutagenicity, teratogenicity

CHRA Manual Guideline Second Edition,
Occupational Safety and Health (Use and Standard of Exposure of Chemicals Hazardous to Health) Regulations, 2000

According to USECHH Regulations 2000, any chemicals including heavy metals that are listed in Schedule II, are considered as chemicals hazardous to health. Not all types of heavy metals are listed in this schedule, therefore, only listed heavy metals are summarized based on acute and chronic effects inTable 4.2 below. The table explains on how dangerous the heavy metals are and each of heavy metal can affect most of human body parts including organs.

Table 4.2: **Acute and chronic health effect of heavy metals**

Heavy Metal	Acute Effect	Chronic Effect	
		Body Parts	**Description**
Arsenic	Throat constriction, dysphagia, epigastric pain, vomiting, abdominal pain and watery diarrhea	Skin	Pigmentation, skin cancer
		Hair	Hair loss
		Respiratory	Chronic bronchitis, lung cancer
		Liver	Chronic hepatitis
Cadmium	Fever, gastrointestinal tract irritation	Nervous system	Coma
		Kidney	Tubular damage
		Kidney	Renal dysfunction, kidney stone

Table 4.2continued

Heavy Metal	Acute Effect	Chronic Effect	
		Body Parts	Description
Chromium	Dermatitis, conjunctivitis, anorexia, chest pain	Skin Lung	Chrome ulcers Bronchitis, pneumonitis
Lead	-	Abdomen	Mild-anorexia, epigastric discomfort
		Nervous system	Rarely paralysis, slow mental changes
		Kidney	Chronic nephritis, tubular damage
		Other	Damage to fetus
Manganese	Dermatitis, fever	Nervous system	Damage to central nervous
		Lung	Pneumonia, chronic bronchitis
Mercury	Chest pain, cough, gastrointestinal tract irritation	Skin Eye Abdomen Other	Erythrism Mercurialentis Stomatits Weight loss, insomnia
Nickel	Respiratory tract irritation, fever	Skin Nervous system	Severe dermatitis, eczema Loss sense of smell
		Nose Lung	Nasal sinuses Asthma, lung cancer

Guideline on Medical Surveillance
Occupational Safety and Health (Use and Standard of Exposure of Chemicals Hazardous to Health) Regulations, 2000

Other than disease affected from drinking water, direct contact from wastewater containing heavy metals is also needs special attention and there are cases reported regarding this problem. The first case study was reported by Rao Muhammad Saqiba et. al that evaluate the patient from Civil Hospital Hyderabad, India through interview. The patient was a boy that suffers from skin irritation and diarrhoea due to the presence of high concentration of mercury and arsenic(Rao Muhammad Saqiba, Zunaira Memona, Fida Siddiquib, Ashfaque Pathanb, & Memon, 2018). Other study is focused on the skin diseases from the agriculture activities that the main source of water is from the river. The river is from Kim Nguu River and Red River located at Hanoi, Vietnam,where the wastewater discharged at. There were several symptoms reported including skin itchy, rash, red papules, skin chaps and unhealed wounds which give percentage of 90.7%, 42.6%, 34.3% and 16.7%, respectively(Trang, Mølbak, Cam, & Dalsgaard, 2007).

Based on findings, the case studies proved that this is considered as serious issue that need to take into account. This is because direct contact from daily activities as mentioned above may have immediate effect especially to skin and eye. People especially in rural area in certain parts of the country are still doing these daily activities. Therefore, proper wastewater treatment is extremely needed to solve these problems.

4.2 Electrophoretic Deposition (EPD)

Electrophoreticdeposition (EPD) is revealed in 1808 by Ruess, the Russion scientist and the first patent for the use of electrophoretic painting is awarded on 1917 to Davey and General Electric. Afterwards, this technique has been extended to be used in some other applications such as the deposition of rubber latex, the coating process, the ceramics process and nanotechnology processes (Corni, Ryan, & Boccaccini, 2008). This technique has two main benefits; the obtained water will be free of pollutant and the heavy metals from the water could be specifically captured without involved the separation process.

Deposition of heavy metals by using EPD is mainly controlled by electric field. This parameter is found to be significant to EPD since it influencing the particles to be separated from the water and deposited to the electrode. In relation to this, repulsion between particles during deposition process may be avoided by the development of enough force by an electric field (Begoña Ferrari & Moreno, 2010). Beside, the performance of EPD is also depending on the suspension. Stable suspension is the key factor and needs to be taken into account because it may affect the formation of heavy metals deposit trough the suspension conductivity (B. Ferrari & Moreno, 1996, 1997). In addition, the optimum condition of this process also varied based on the desired heavy metals.

4.2.1 Principle of Metal Nanoparticles by Influencing of Electric Field

Colloidal particle is uniformly dispersed particles that are not truly dissolved but yet do not settle readily. It is stable due to its small size electrostatic repulsion. There is a present no simple or standard procedure to specifically determine the colloidal matter. Most colloids are not easy to settle down even with a long period of settlement. Many colloidal particles remain suspended in wastewater because of their small size and electrostatic repulsion. Electrostatic repulsion is the mechanism of particles that controlsstability. At the interface of the hydrophobic surfaces, excess anions and cations may accumulate. With hydrophilic surfaces, surface charge exists and interact ions with the opposite charge of surface. The electrostatic and van der walls forces strongly bind this ion to the surface. The layer of accumulated ions of the surface produces an electrical potential that repels particle from each other and causes the particles to remain suspended in water.Most particles in water exhibit a net negative surface charge. So, the negative surface charge together with van der walls forcesof attractionthe layers of ion next to the particle surface and built an electrical potential which prevents particle from agglomerate into larger particles(Azari, Abolghasemi, Hosseini, Ayatollahi, & Dehghani, 2018; Fei, Gu, & Bishop, 2017; Schreuer, Vandewiele, Strubbe, Neyts, & Beunis, 2018).

Prior understanding the principle of particle movement by the electric field, the basic of molecular and atomic level of the particles is the first part to be discussed. The goal is to discuss the relationships between molecular structure and reactivity. These relationships have their basis in the fundamental physical aspects of molecular. As a part of molecular, atoms are the smallest things could be seen but not with the naked eye, only by scanning, tunnelling and by using microscope. To really understand the concept of reactivity, the Bohr model is an approach that can be used to describe it.

The Bohr model, also known as Rutherford-Bohr model was introduced by Niels Bohr and Ernest Rutherford in 1913 to understand the basic structure of the atom. This model is also known as planetary model to modelling the part of atoms as illustrated in Figure 4.2. As can be seen in Figure 2.1, atoms consists of protons and neutrons and these forms the nucleus of the atoms. Orbiting the nucleus are the electrons and these electrons are responsible for electricity. It also can consider the orbit as shells surrounding the nucleus. One type of atoms is the elements as stated in the periodic table that defines the number of protons in the nucleus at the centre. Atoms of one element may have the same number of protons but can have different numbers of neutrons and electrons. Electrons which are far lighter with the protons in the nucleus can relatively easily move and this is important because the movement of electrons is performing an electric current. The atoms protons account for the positively charged of the nucleus, while the electrons for the negative charged. In a stable resting or known as neutral electrical condition, these charges balance each other out within the atoms. This gives the atoms a net electric charge of zero. In this stage, it is the lowest possible energy level, which is called the ground state of the atoms. However, the charge or energy level of atoms could be changed by causing it gain or lose electrons. When the atoms have fewer electrons than protons, it becomes positively charged. But when the atoms have more electrons than protons, it becomes negatively charged. In the ground state or when there is no charge, it is called an atom. However, when there is a charge, it becomes an ion; positive and negative ions. This is how the electric field influence the movement of the atoms, which also known as elements or metal particles. The concept of this phenomenon could be applied for particle movement in aqueous suspension(Budaca, Buganu, & Budaca, 2018; Georgoudis, 2014).

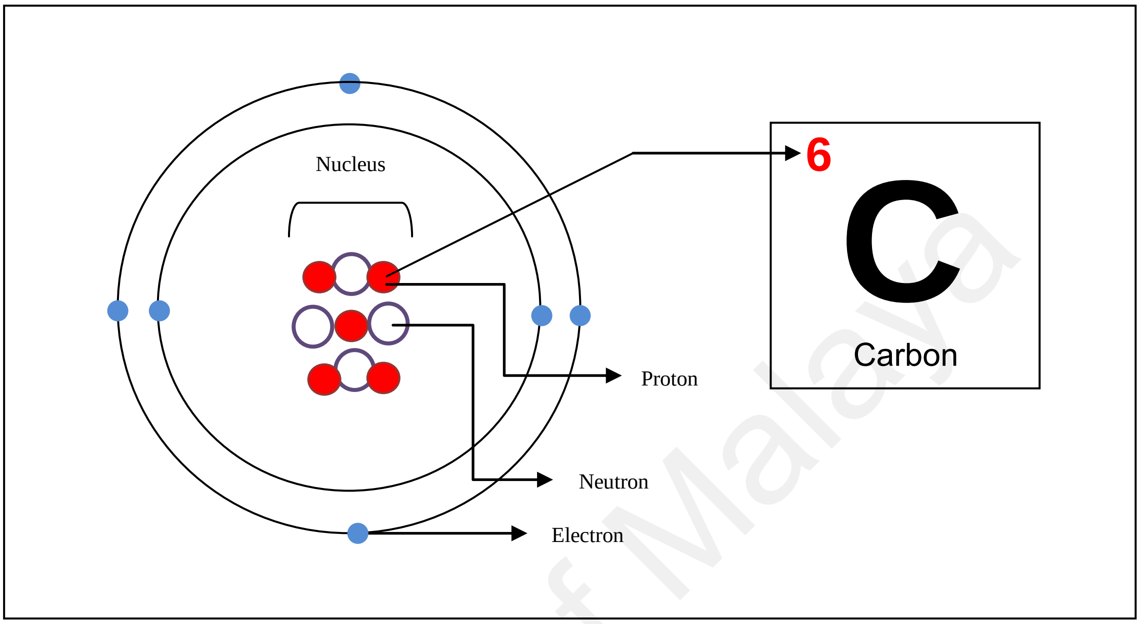


Figure 4.2: **Bohr Model or Planetary Model for the Atoms**

Based on the Bohr model, the opposite charge attract between atoms must be created in order to stimulate the driving force. As a rule, electrons will flow from atomic centres which have high in electron density to atomic centres low in electron density. The electric fields are well-suited to induce local electro-kinetic phenomena of various natures which can be used to drive the motion of particles along the field lines or to promote and control particle interactions (Lauren et. al, 2016). The force intensity and direction depends on the particle size as well as the dielectric properties of the particle and the surrounding medium (Zhang C., 2010). In addition, polarity also plays an important role for particle movement.

4.2.2 Mechanism of EPD

The mechanism of EPD has been explained by different researchers based on the experimental results and the most accepted mechanism is introduced by Sarkar and Nicholson (Mishra et al., 2010). They stated that EPD is the process of colloidal particles and regularly carried out in two electrode cells that dispersed in suspension medium with the existence of electric field, as shown in the Figure 2.2(Sarkar P & Nicholson, 1996).

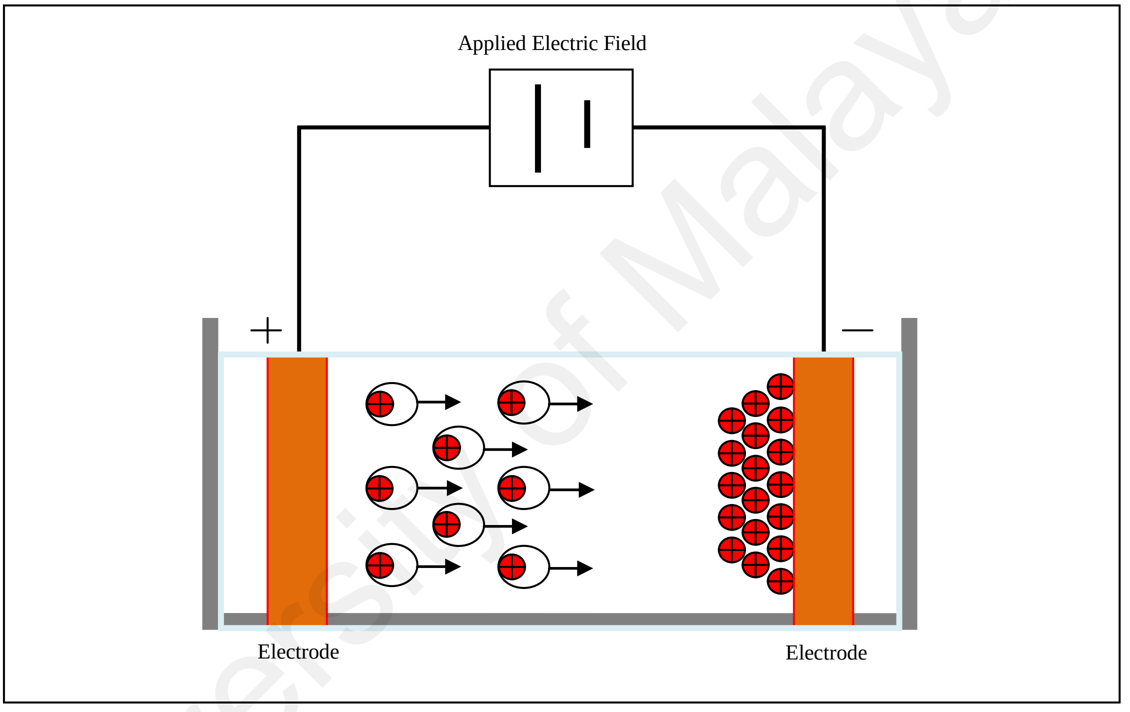


Figure 4.3: The mechanism of EPD

The metal nanoparticles in wastewater are found in the various conditions. Basically, they are formed in several sizes and most of them are tend to settle due to gravity as shown in Figure 4.4 (a).According to (Corni et al., 2008), it is important that the particles remain completely dispersed and stable for homogeneous and smooth deposition. It is difficult to get uniform deposition from sedimenting suspension of large particles. Therefore, in order to effectively apply this technique, it is good to consider a stable suspension containing charged particles free to move when an electric field is applied.

The mechanism of EPD involves two main steps; electrophoresis and deposition.(Diba, Fam, Boccaccini, & Shaffer, 2016). Firstly,the colloidal of charged particles between two electrodes in the suspension occurs when the electric field is applied, which this process is called electrophoresis. In this process, the particles in the aqueous suspension could move independently, and the electrochemical equilibrium between suspension and particles produce the surface charge of the particles. Secondly, the existence of electrophoretic force would help the transportation of the particles in the suspension and the deposition of material started to begin when the particles create compact and uniform layer to the electrode (Ogata, Van Tassel, & Randall, 2001; Vandeperre, 1999). The process involve in the suspension as medium for particle motion and therefore, a stable suspension is important for the movement of the charged particles being smooth to produce efficient process (Corni et al., 2008).

In electrophoresis process illustrated in Figure 4.4 (b), there are two main principles for the function of electric current, which are based on the electrode and the suspension. In the electrodes, electric current is carried by the movement (colloidal process) of electrons along the surface of the electrodes. In suspension, the electric current flows between electrodes that are carried by ions. The ions that transported to the anode (negative charge of ions) are called “anions” while the ions that transported to the cathode (positive charge of ions) are called “cations”. The colloidal of particles in the suspension is being the crucial part before deposition can be produced(Drabik, Bodzoń-Kułakowska, & Silberring, 2016).

The deposition occurs when the particles are near to electrode as shown in Figure 4.4 (c), therefore the electrophoresis at this point needs to be considered. When far from electrode, the particles must able to move without any force except force from the electric field (James H. Dickerson, 2012). The main properties of colloidal system are interaction between particles in the suspension, size, shape and the surface of the particles. The particles surface includes the charge, adsorption etc. Other than properties that should take into account, colloidal system also has an issue, which is the separation surface between the dispersed phase and the dispersing medium (Cosgrove, 2005). Therefore, it is important to consider and study the state of both properties before the process due to interaction between them.

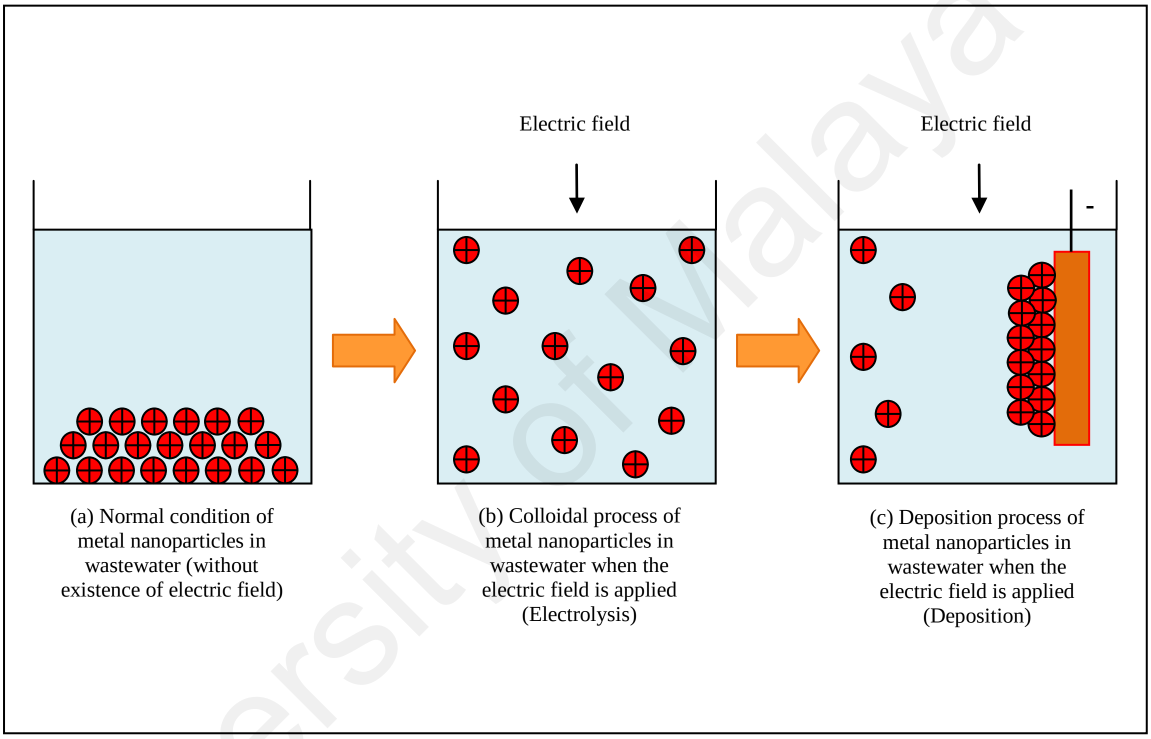


Figure 4.4: Particles conditions before and during EPD process

4.2.3 EPD Process Parameters

The efficiency of EPD process is depending on the parameters involved; (i) suspension relating parameters such as particle size, conductivity and zeta potential (Begoña Ferrari & Moreno, 2010) and (ii) process relating parameters include pH, and current. These parameters are related to each other to produce excellent deposition process (Besra & Liu, 2007).

4.2.3.1 Particle Size

In EPD, there is no specific size of particles is necessary to proceed with the process, but (Heavens, 1990)have found that the stableand homogeneous suspension may lead to successful of EPD and he stated that the good deposition may occur if the particles in the range of 1-20um. The main idea is to make sure that the particles are in homogeneous condition for smooth process of deposition. The larger size of particles may cause sedimentation due to its gravitational force and the efficiency of deposition is become low. Differ with smaller size of particles; if the particles are too small, the particles are possible to float at the surface of the suspension and also affected the deposition rate. Therefore, the movement of the particles is not only depending on the size, but other parameters are needed to improve the formation of deposit.

4.2.3.2 Conductivity

The stability of suspension is based on the rate of settling and flocculation process and stable suspension means; no flocculation will occur and the particles to settle slowly. The conductivity of the suspension has been studied by Ferrari and Moreno and they stated that it is the crucial part in EPD experiment. Based on the study, there are two main point which are; (i) the movement of the particles became slow if the suspension is too conductive, while (ii) the stability will loss if the suspension is too resistive (B. Ferrari & Moreno, 1996). Therefore, the conductivity may not be suitable at all range in EPD technique cause the forming of deposit to be limited. However, this technique may be successful with the applied of current (B. Ferrari & Moreno, 1997) that will be discussed later.

4.2.3.3 Zeta Potential

The parameters of suspension consist of several aspects such as the nature of suspended particles and the liquid medium, the particles surface properties and dispersant. There are various types of aqueous suspension medium and in this case, water is the main consideration because the main objective of this research is to remove and capture heavy metals from wastewater. Generally, the occurrence of water hydrolysis is considered as normal process when water is used as suspension medium in EPD. Hydrolysis is the process when the bubbles occurred will be trapped within the deposit. In aqueous suspension, mixing up water and ethanol as co-solvent may reach EPD. However, the addition of alcohol as co-solvent may result inexpensive process (B. Ferrari & Moreno, 1997; Santillán, Quaranta, & Boccaccini, 2010). The experiment proved that water hydrolysis could be avoided when low rate of voltage is applied (Santillán et al., 2010).

Beside the stability of the suspension, the particles stability also needs to be considered and the parameter that relate to particles stability is zeta potential (Kadam, Sinha, Kalubarme, & Pawar, 2009; Novak & König, 2009; Santillán, Caneiro, Quaranta, & Boccaccini, 2009). The role of zeta potential is to stabilize the suspension by determining the intensity of repulsive interaction between particles and the movement of the particles based on the electrostatic force that keeps the particles "floating" in the suspension (James H. Dickerson, 2012). The electrostatic and van der Waals force are the main mechanism that affects this interaction. The additive of charging agents such as acids and bases into the suspension could control the zeta potential because the influence of these additives may relate the driving force of the particles of the suspension (M. Zarbov, 2004). The deposition rate is dependent on the zeta potential, therefore, the charging agents may help the particles to be transported to the electrode, and form deposit. Due to that, it is good if zeta potential is analyzed before the EPD is carried out.

4.2.3.4 pH of suspension

The efficiency of EPD is also considering pH as one of the parameter as the pH is related to zeta potential proportionally. It means that when the pH increase, the zeta potential is also increase. The EPD mobility and rate in the suspension can be controlled by using variation of zeta potential, which also can control the performance of EPD. Most of the studies have found that these variations can be done by the addition of acidic agents into the suspension (Hanaor et al., 2011; Hasanpoor, Aliofkhazraei, & Delavari H, 2016; Yokoyama, Suzuki, Motomiya, Takahashi, & Tohji, 2018). Acidic agents may lower the pH value in the suspension and can strongly impart negative value of zeta potential, and this situation will improve the mobility of EPD. The low level of pH value may also lower the possibility of electrolysis which generate gas bubbles during the EPD process (Hanaor et al., 2011)

4.2.3.5 Current

The uniformity of particles is one of the major considerations to produce effective EPD and this can be achieved by the addition of current during the process (Gardeshzadeh, Raissi, & Marzbanrad, 2008). There are two types of current that can be used in EPD, which are direct current (DC) and alternating current (AC). According to Naim et. al, uniform particles can be obtained by using pulse DC rather than conventional DC. It is due to the on-off mode will de-agglomerates the particles and allow faster movement of particles(Naim et al., 2010). Other than using acidic agents, pulse DC may also reduce the formation of bubbles generated from water electrolysis(Besra, Uchikoshi, Suzuki, & Sakka, 2010).

Beside DC, there are also studies that focusing on AC during EPD. AC involves the movement of electric charges that periodically reverse direction (Alejandra Chávez-Valdez & Boccaccini, 2012). Neirinck et. al claimed that the formation of gas bubbles may also reduced by using AC in EPD. The use of AC will cause the strength of electric field to be improved, causing the particles to travel a long distance. Furthermore, it enables to produce smooth deposition with thick film(Neirinck, Fransaer, Biest, & Vleugels, 2009).There are other considerations for smooth movement of particles, which are by the addition of signal's shape and frequency. High frequency is needed to avoid formation of bubbles and the study shows that the relationship between AC and high voltage may cause the EPD to be effectived(A. Chávez-Valdez, Herrmann, & Boccaccini, 2012; Raissi, Marzbanrad, & Gardeshzadeh, 2009; Yoshioka, Chávez-Valdez, Roether, Schubert, & Boccaccini, 2013).

4.3 Captured Heavy Metals

The captured heavy metals by using EPD technique is summarized in Table 4.3:

Table 4.3: Experimental work on captured heavy metals by using EPD

Type of Heavy Metal	Type of Suspension	Parameters							Result	Reference
		Type of Electrode	Type of Current	pH	t (mins.)	Current (A)	Voltage (V)	Frequency (Hz)		
Iron	Tap Water (No stabilizer added)	Carbon Plate Carbon Fiber	DC	7.15	10	2 – 4	5	-	Removal: 58%±2.17 Removal: 96%±1.42	(Mohd Sharif, Abu Bakar, & Naim, 2015)
	Portable Water (No stabilizer added)	Carbon Plate Carbon Fiber	DC	-	10	-	<25	-	Removal: 26%-56% Removal: 80%-87%	(Naim et al., 2016)
Zinc	Ethanol (Addition of zinc nitrate salt)	-	DC	-	3	-	40	-	Deposition Mass: 0.91mg Value of Porosities: 4.5% Surface Density: 0.095mg/cm²	(Hasanpoor et al., 2016)
	Ethanol (Addition of magnesium nitrate)	Steel Sheet	DC	-	-	-	10, 20, 30	-	Film Thickness for Nanosheets: 26nm Film Thickness for Nanorods: 139nm	Mohammadi, et al. 2018)

Table 4.3 continued

Type of Heavy Metal	Type of Suspension	Parameters							Result	Reference
		Type of Electrode	**Type of Current**	**pH**	**t (mins.)**	**Current (A)**	**Voltage (V)**	**Frequency (Hz)**		
Copper	Deionized Water (Addition with Citric Acid)	Glass Covered with ITO Platinum Plate	DC	3.0	1-3	-	-	-	The weight of copper nanoparticles increased linearly with time	(Yokoyama et al., 2018)
	Acetone	Gold Coated Glass	AC	-	10	-	40	100	Deposition yield of carbon nanotubes decreased as frequency increased	(Alejandra Chávez-Valdez & Boccaccini, 2012)
Titanium	Deionized Water	316L Stainless Steel Foil	AC	~4	5	-	5	100	Homogeneous and smooth surface of deposit	Chávez-Valdez, et al. 2012)
	Deionized Water	316L Stainless Steel Foil	DC	-	1	-	5	-	Damage surface of deposit due to the existence of gas bubbles	
	Ethanol	316L Stainless Disk	DC	-	5	-	30	-	Successfully deposited	(Dhiflaoui et al., 2017)

Table 4.3 continued

Type of Heavy Metal	Type of Suspension	Parameters							Result	Reference
		Type of Electrode	Type of Current	pH	t (mins.)	Current (A)	Voltage (V)	Frequency (Hz)		
Titanium	Distilled Water (Addition of various types of acidic reagent)	Gold Foil Strip Graphite Substate	DC	-	10	-	10	-	The lower value of pH will increase the deposition rate	(Hanaor et al., 2011)
	Isopropanol	TiO_{2-x} Scaffold Titanium Plates	DC	-	20	-	20	-	The uniform deposition obtained	(Narkevica, Stradina, Stipniece, Jakobsons, & Ozolins, 2017)

The general ideas in the applications of EPD technique are focusing on the recent published research. There are numbers of experiments done by researchers and this anyhow is concentrating the study of deposition of heavy metals in aqueous suspension. The applications that are based on the experiment may facilitate the improvement of EPD process by the influence of process parameters. Table 4.3 below summarizes the captured heavy metals by using EPD from previous studies.

Based on the experiment, the fine iron-oxide particles are successfully removed up to 96% by using carbon fiber, while 58% by using carbon plate. This is due to high surface area that also plays an important role in EPD process. The deposition layers of both electrodes are confirmed by using EDX analysis to prove the existence of fine iron-oxide. Beside, the direct current (DC) is applied during the process with variation of voltage from 5V to 25V. The result shows that the high efficiency of removing metals is at 5V. This is due to the higher the voltage, the more bubbles is produced (L. Besra, T. Uchikoshi, T.S. Suzuki, & Sakka, 2009). In relation between applied voltage and deposition process, the deposition rate will be reduced with the existence of bubbles in the suspension, which the process is called hydrolysis (Mohd Sharif et al., 2015).

Differ with other researcher, (Naim et al., 2016) that study the potential on removing and depositing the permeated iron-oxide particles by using EPD. The main objective is to emphasize the possibility of EPD to remove and deposit the iron-oxide after filtration process due to extremely low in concentration found in portable water. This study is concerning on the permeation of iron-oxide particles and surface charge of the particles after passing the membrane. The experiment is conducted by using carbon plates and carbon fibers as an electrode with the applied of direct current (DC) with three different values of voltage for comparison purposes. It is proved that the removal of iron-oxide occurs when the voltage of <20V is used resulting efficiency up to 87% of removal for the use of carbon fiber, and 56% for carbon plate. Based on result obtained, the EPD technique could also to be used for very low concentration of metals in water.

Beside iron oxide, zinc oxide is also being concerned for researchers due to its various applications include semiconductors, optical and photo-catalytic fields (ref no. 1& 2 in in-situ paper). The study of zinc oxide nanopraticles by using EPD has been conducted by (Hasanpoor et al., 2016). The main focus is to identify the mass and density of deposited film from the electrode after the EPD process by varying the parameters, which are the type of suspension and the applied voltage. Ethanol and methanol are used as suspension in this experiment with the addition of zinc nitrate salt to develop positive charge of nanoparticles and 20 to 40V of voltage is applied. Based on the result, it has been reported that the increasing of voltage resulted the increasing of deposition mass, values of porosities and surface density of the deposited film by using ethanol as a suspension. It is proven that the voltage will increase the velocity of the nanoparticles in the suspension and at once the number of nanoparticles surrounding the electrode is also increase.

Furthermore, this research has been supported by (Mohammadi, Aliofkhazraei, & Rouhaghdam, 2018) that narrowing the objective by identifying the effect of morphologies of zinc oxide by using zinc oxide nanorods and nanosheets. These are the types of zinc oxide with different shape and form that both are converted into powders by certain procedures and the powders are then suspended into the suspension prior the EPD process. From the table, the film thickness of zinc oxide nanosheets and nanorods gives huge difference of measurement. The experiment has been furthered by using FESEM and the results show that the deposition rate of zinc oxide nanosheets is higher compared to nanorods due to its homogeny of surface area. Therefore, the characteristics of the nanoparticles also play an important role for deposition process.

(Dhiflaoui et al., 2017) claimed that the deposition has successfully occurred with the conditions stated above. The study furthered by considering the mechanical properties of the nanoparticles through the addition of heat in air after the deposition process as thermal treatment. The heat will improve the surface and the coating structure of nanoparticles. Based on the result, the porosity on the surface decreased as the temperature increased. The uniformity of the surface that deposit to the electrode is depending on the time and voltage at the same time. If the deposition time is too long, non-uniform surface will occur due to increasing of deposition resistance (Narkevica et al., 2017).

Beside the characteristics of nanopartcicles, the condition of suspension may alsotake into account. The addition of citric acid in the water is used as a surface stabilization and at once the suspension will also stable even with the existence of electric field. However, when the pH is too low, the absorption of citric acid into the nanoparticles may occur while desorption occur when the pH is too high (Yokoyama et al., 2018). Other study of suspension is done by (Hanaor et al., 2011). The study is narrowing the condition of suspension based on the connection between zeta potential, pH and the charge of nanoparticles. The efficiency of deposition is compared by varying the pH level of the suspension by adding various types of acidity reagents. The in the suspension is identified. The result obtained shows that the deposition rate increased at lower pH level.

EPD by using direct current (DC) has been carried out by most of researchers. However, there is also review on EPD by using alternating current (AC). The pattern and yield of deposition are obtained from the result when the frequency is applied. The deposition occurred at i) surface of electrode and ii) the gap between the electrode by varying the frequency. As the frequency increased, the yield of deposition will decrease and the deposition occurs between the gaps of the electrode(Alejandra Chávez-Valdez & Boccaccini, 2012). Other researchers have make comparison between AC-EPD and DC-EPD. They reported that the deposition by using AC resulted smooth and uniform surface while damage surface is obtained when the DC is applied due to the existence of gas bubbles in the suspension. However, from the result, both AC and DC give the similar conclusion that the number of amount and size of crack on the deposition surface increased as the voltage increased (A. Chávez-Valdez et al., 2012).

Based on the result, the optimum conditions of EPDhave been obtained as shown in Table 4.4 and it can be applied into the wastewater treatment. These parameters are basically selected based on the removal efficiency, deposition mass, deposition rate and the uniformity of the surface after the EPD process.

Table 4.4: **Optimum condition of EPD**

Parameters				
Type of Current	**pH**	**t (mins.)**	**Current (A)**	**Voltage (V)**
DC	< 7	3-20	2-4	5-30

CHAPTER 5

CONCLUSION

This review has focused on the studies ofEPD technique in capturing heavy metals in industrial wastewater. Based on the observation result and discussion, the industrial wastewater effluent is found to be the most hazardous waste which can significantly affect to human health and environment.The relatively high level of contamination in wastewater is heavy metals.The major heavy metals that mainly found in industrial wastewater are cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), iron (Fe), zinc (Zn), mercury (Mg) and manganese (Mn).It is proven that the health risk such as skin diseases, diarrhoea and cholera are the common diseases found that affected from heavy metals.The higher concentration of heavy metals in wastewater, the poor health effects are found correlated. Beside human health, heavy metals may also cause damage to the environment, where the expansion of damage effect ismainly contributed by the irrigation process. These issues haveconfirmed that a serious concern to remove the heavy metals from industrial wastewater by using the environmentally friendly technology is crucially important.

It is apparent from this review that EPD technique has a high removal efficiency of heavy metals based on the previous studies. This technique is recommended to be installed as a part of wastewater treatment process in industry. This recommendation was proposed based on its ability to recover high value of heavy metals from the deposition process, simple setup of unit process and no secondary pollution is generated. In addition, the successful of EPD is lies on the stability of particles in terms of colloidal and unagglomerated phenomena's.

The practicality of EPD is still in a limited number of studies and the trial and errors optimization process is required. The benefits from the advantages include cost effectiveness, versatility and ease of application are the precondition to help the improvement of EPD in scaling-up the process and the ability to implement it into the industrial wastewater treatment.

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