LANDFILL LEACHATE TREATMENT BY COAGULATION FLOCCULATION USING TWEEN80

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By

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I hereby declare that all corrections and comments made by the supervisor(s)and examiner have been taken into consideration and rectified accordingly.

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ABSTRAK

Tapak pelupusan mempunyai beberapa komponen larut lesap yang sangat toksik, menghakis, berasid dan mencemarkan alam sekitar. Bahan larut lesap ini juga mempunyai ciri tersendiri kerana ia boleh berubah-ubah dan mempunyai kuantiti bahan yang tidak diperlukan daripada sisa sangat tinggi. Kajian ini dijalankan untuk mengkaji kebolehrawatan larut lesap separa-aerobik melalui pengentalan dan pemberbukuan menggunakan surfaktan. Larut lesap daripada Tapak Pelupusan Pulau Burung (TPPB) Penang telah dipilih sebagai lokasi kajian. Kesan daripada pH dan dos koagulan dalam mengurangkan keperluan oksigen kimia (COD), kekeruhan dan zink dinilai menggunakan ujian balang. Beberapa siri ujian balang telah dijalankan untuk bancuhan pantas selama 1 minit pada 250 rpm, diikuti dengan bancuhan perlahan selama 5 minit pada 50 rpm dan proses mendapan mengambil masa selama 30 minit. Berdasarkan kajian, keperluan oksigen kimia (COD) memberi kepekatan sebanyak 3307 mg/L dan BOD_5/COD sebanyak 0.07, maka larut lesapan dari TPPB boleh dikategorikan sebagai larut lesapan yang stabil . Potensi zarah dan saiz zarah juga dibincangkan dalam kajian ini. Berdasarkan keputusan, pH 2 sangat berkesan untuk menghilangkan COD dan zink, manakala pH 12 berkesan untuk menghilangkan kekeruhan. Kajian ini juga menunjukkan bahawa pelarasan pH memainkan peranan penting sepanjang proses pengentalan dan pemberbukuan terutamanya dalam pengagregatan dan pengasingan zarah.

ABSTRACT

A landfill may include a number of leachate components that are very toxic, corrosive, acidic, and pollute the environment. These leachates are also distinctive in that they are very changeable and include considerably higher quantities of waste-derived unwanted material. This study was to investigate the treatability of the semi-aerobic landfill leachate via coagulation-flocculation using surfactants. The leachate at Pulau Burung Sanitary Landfill (PBSL) in Penang was chosen as the study location. The impact of pH and coagulant dosage on the removal of chemical oxygen demand (COD), turbidity, and zinc was investigated utilising jar test equipment. A series of jar tests were performed, beginning with 1 minute of rapid mixing at 250 rpm, followed by 5 minutes of slow mixing at 50 rpm, and 30 minutes of settling. Based on the results, chemical oxygen demand (COD) gives a concentration of 3307 mg/L and a BOD_5/COD of 0.07, therefore, leachate from PBLS may be categorised as stabilised leachate. The zeta potential and particle size measurement also were discussed in this study. According to the results, pH 2 is very effective at removing COD and zinc, whereas pH 12 is effective at removing turbidity. This study demonstrated that pH adjustment played a significant role throughout the coagulation and flocculation processes, particularly in particle aggregation or disaggregation.

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LIST OF ABBREVIATIONS AND SYMBOLS

TPPB	Tapak Pelupusan Pulau Burung
PBSL	Pulau Burung Sanitary Landfill
MSW	Municipal Solid Waste
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
Zn	Zinc
USM	Universiti Sains Malaysia
NSWMD	National Solid Waste Management Department
GHG	Greenhouse Gas
TDS	Total Dissolved Solid
TOC	Total Organic Carbon
$N\text{-}NH_3$	Ammoniacal Nitrogen
O_2	Oxygen
CH_4	Methane
CO_2	Carbon dioxide
SBR	Seuencing Batch Reactor
$FeCl_3$	Ferric Chloride
$AlCI_3$	Aluminium Chloride
$ZrCl_4$	Zirconium
DOM	Dissolved Organic Matter
H_2SO_4	Sulphuric Acid
NaOH	Sodium Hydroxide
DLS	Dynamic Light Scattering
SS	Suspended Solid
APHA	American Public Health Association
ha	hectare
rpm	rotation per minute

min	minute
mV	miliVolts
mg/L	miligram per liter
NTU	Nephelometric Turbidity Unit
N	North
E	East
L	Liter
M	Molar
mL	mililiter
g	gram
°C	degree Celsius
d.nm	diameter values in nanometer

CHAPTER 1

INTRODUCTION

1.1 Background

Municipal solid waste (MSW) management has emerged as a major concern in global development plans, particularly in rapidly growing cities. Malaysia is often regarded as one of the most successful economic growth. Malaysia is classified as a developed country because of its constant economic development and low unemployment rates, which are powered by stable political conditions and a plentiful supply of resources. Malaysia is undergoing fast industrialisation and urbanisation, which is having a negative impact on the environment due to an increase in waste generation. Rapid urbanisation and industry in Malaysia, like in many other nations, have altered the solid waste generated characteristics. Furthermore, waste generation rates rise as Malaysians' need for a higher standard of living rises. Inadequate and poorly run facilities lead to environmental pollution and harm public health due to a lack of solid waste planning and financial investment in waste management (Shahril, 2020).

Solid waste is a huge environmental issue in Malaysia, drastically diminishing our environment's capacity to sustain life. The quantity of waste created is rising over the years, yet less than 5% of waste gets recycled. Human activities generate solid waste, which is classified into numerous types. For example, household, industrial non-hazardous, and commercial solid wastes, as well as non-hazardous sludge, are typically disposed of at urban solid waste landfills (Mojiri et al., 2021). Food waste, plastic, metal, rags, glass and paper are the major components, as well as small quantities of hazardous waste such as batteries, medical waste, automotive parts and electronics are frequently included in collected waste (United Nations Economic and Social Commission for Asia and the Pacific, 2002). Aside from the significant growth in waste management system expense, the method in which these wastes were treated may have negative consequences on the environment and public health (Ferronato & Torretta, 2019).

Waste can be treated in various ways, including incineration, composting, and landfilling. Landfilling is the most popular method of waste disposal. It is recognised as an important solution today or in the near future, particularly in poor and middle-income nations, because it is the simplest and cheapest existing technology (Ismail, 2013) .

Landfilling reduces the environmental impact of other waste disposal methods by allowing waste to decompose under controlled conditions until it is transformed into stabilised waste. However, the combined effect of rainwater percolation and natural fermentation of landfilled waste results in the formation of a highly polluted liquid and biogas. Biogas can be used to generate energy, while highly contaminated leachate must be treated so that it does not pollute surface and groundwater.

Landfill leachate is produced as a result of precipitation, surface run-off, and groundwater infiltration or intrusion percolating through a landfill (Zaini et al., 2019). As a result, landfill leachates characteristics result from a complex combination of factors such as soil properties, weather conditions, municipal solid waste composition, landfill age, and landfill operation. Leachates contain a high concentration of organic matter (biodegradable, but also refractory to biodegradation), primarily humic acids, ammonia nitrogen, organic and inorganic salts, and trace elements. The volume and type of leachate created by a landfill site will vary depending mostly on the site's age

(Vaverková, 2019) and the stage of biodegradation reached. Because leachate composition changes over time, leachate control systems must adapt to these changes. Therefore, leachate treatment is necessary to eliminate any contaminating components and bring the leachate to a standard that allows it to be released to a sewer, a water channel, land, or tidal water.

Overall, this study will focus on the effects of surfactants to reduce the parameters in leachate by using jar test. Surfactants (surface active agents) are amphiphilic molecules with two distinct parts: a hydrophilic group and a lipophilic group (Anestopoulos et al., 2020). They can be broadly defined as compounds that change the energy relationships at interfaces, frequently by changing the surface or interfacial tension (Achparaki et al., 2012). Surfactants are manufactured in a wide range of concentrations in continuously operating plants, depending on their intended use.

1.2 Problem Statement

As the population rises, rising waste creation, urbanisation, and open dumping due to the scarcity of disposal capacity causes environmental problems. As a result, waste disposal by landfilling is getting increasingly challenging as existing landfill sites are rapidly filling up. Simultaneously, construction of new landfill sites is becoming increasingly difficult due to land limitations, higher property costs, and growing adoption, particularly in urban areas due to population development. Landfill leachate is generated by solid waste landfilling. Landfill leachate, if not treated and properly disposed of, might be a possible cause of surface and ground water contamination, since it may seep through the soils and sub-soils, polluting the receiving water (Mohamad Anuar Kamaruddin et al., 2015). This is because of its high organic, inorganic, and heavy metal content and toxicity, which makes the municipal landfill leachate one of the most serious environmental issues. Moreover, surfactant problems in the wastewater treatment process are often underappreciated. This is due to the widespread use and variety of surfactants, and their harmful influence on the wastewater treatment process and, more crucially, the environment. Most of the research commonly focuses on removing surfactants from wastewater instead of using surfactants to reduce the chemical parameter in leachate treatment.

However, among the chemical unit processes currently used in wastewater treatment, coagulation- flocculation has gained a lot of attention due to its excellent pollutant removal effectiveness and easy implementation (Tunc, 2020). This technique may be applied directly to wastewaters without being impacted by the toxicity of the wastewater, and it might be a simple, selective, and economically viable alternative.

1.3 Objectives

The objectives of this thesis work are :

1) To determine the efficiency of Tween80 in coagulation flocculation and the optimum dosage and pH for treating the leachate.

2) To study the effect of the operating parameters on the removals of COD, zinc, and turbidity and to assess the influence of the particle size and zeta-potential of the colloidal fraction in leachate on Tween80 performance.

1.4 Scope of Study

The entire project would begin with information gathering and theoretical study. The initial stage in this research would be to collect a sample from a possible industry, followed by the identification of different forms of coagulants and flocculants. Following that, the strategy will be designed based on step-by-step techniques for finding, investigating, and analysing coagulants and flocculants. After that, experiments will be carried out to correlate theoretical understanding with practises. The research involves the use of analytic coagulants and flocculants, as well as jar testing. Meanwhile, additional research and development would be carried out on a continuing basis to assure satisfactory results.

Since the nearest landfill to USM is the Pulau Burung Landfill, thus, the leachate samples will be collected there as the experiment samples. The parameters that are to be tested includes pH, BOD (Biochemical Oxygen Demand), COD (Chemical Oxygen Demand), turbidity ,zeta potential, particle size and zinc (Zn). The scope of this project is to reduce the parameters using the surfactants in order to determine the water grade discharge to environment.

1.5 Significance of the Study

Due to its large contaminating loads such as organic matter and heavy metals, leachate has become one of the key problems of liquid waste treatment engineering, and hence it stands out as one of the areas of greatest attention during landfill management. There have been various publications of research findings and extensive reviews focusing on the formation, composition, characterisation, and treatment of leachate. Most of these publications are concerned with technological elements of leachate treatment and future development potential. Various treatment options for leachate have been investigated over the years. As a result, the purpose of this paper is to investigate the usefulness and efficiency of different natural plants that can be utilised as coagulants and also contribute into new knowledge in terms of mechanism on how the coagulant treat in removing the pollutant.

1.6 Organization of the Thesis

This project report consists of five chapters, as summarized below:

Chapter 1 Introduction

Chapter 1 gives a brief introduction to the study. It comprises the project's background, problem description, purpose, scope, and significance of the study.

Chapter 2 Literature Review

Chapter 2 presents a literature review that covers the municipal solid waste in Malaysia, including the leachate generated, leachate treatment, coagulations, coagulants , flocculants , and jar test.

Chapter 3 Methodology

Chapter 3 breaks down the jar test methodology into details, describes important categories used to evaluate environmental impacts and discusses each parameter of the Pulau Burung landfill leachate.

Chapter 4 Results and Discussions

Chapter 4 Results of evaluation and comparison will be discussed. In the first section, characteristics of leachate are analyzed in detail.

Chapter 5 Conclusions and Recommendations

Chapter 5 The final chapter of the paper, which is a research summary, includes recommendations for future research as well as the findings of this surfactant investigation.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Currently, there are 147 solid waste landfills including 14 sanitary landfills in Malaysia. Malaysians generate approximately 38,699 tonnes of solid garbage per day, or at least 1.17 kg per person, according to the National Solid Waste Management Department. On top of that, approximately 90% of garbage is disposed of in landfills, with only 10% recycled. According to Bernama (2022), the most recent statistics forecasts that 14 million tonnes of garbage will be collected each year in 2022, or about 40,000 tonnes per day, with an estimated 95% of solid waste collected being disposed of at landfills. Besides, because of the widespread use of face masks and COVID-19 self-test kits, which are discarded as household garbage rather than clinical waste, medical waste led to an increase in solid waste disposal when the Covid-19 pandemic began in March 2020.

Municipal Solid Waste (MSW) is generated by households, offices, recreational activities, shops, schools, and other institutions. MSW is primarily composed of food waste, product packaging, glass, plastic, metal, and paper, though demolition and construction debris, as well as small quantities of hazardous waste such as pesticides, batteries, paints, electronic and small appliances, and discarded medicines and chemicals, are frequently included in collected waste. According to National Solid Waste Management Department (NSWMD), paper is the most wasteful waste in landfills, accounting for around 17 percent of total garbage and contributing approximately RM205 million to national income (Bernama, 2022). Plastic is the second most recyclable material "wasted" in landfills, accounting for around 9% of the total, with a potential value of RM163 million.

Nowadays, Malaysia's main challenge is determining how to properly and sustainably handle this ever-increasing MSW. These issues include insufficient garbage collection, recycling, or treatment, and uncontrolled waste disposal in conventional dumps, which results in serious risks and environmental degradation (Johari et al., 2014). When rain falls, for example, it washes away some of these wastes and leachates into water sources such as rivers, exposing the environment to increased contamination risk (*Reduce , Reuse and Recycle (3r) Awareness Programme to Increase the Knowledge , Attitude and Practice on 3r among Primary School Students,* 2022). Greenhouse gases (GHG) are also discharged into the atmosphere from these dumps, adding to climate change, which is another major problem. Among other things, these circumstances cause MSW disposal to be seen as a source of environmental degradation (Johari et al., 2014).

Even more, the predominant method of disposal of MSW is landfill, with the majority of sites being open dumping areas. Open dumping landfills are preferred (Ferronato & Torretta, 2019) because they are the cheapest and most prevalent way of treating solid waste with a high percentage of organic components. However, open dumping spread bad odor and poses a serious threat to the environment and public health (Etea et al., 2021). The generation of landfill gas is one of detrimental impact of open dumping. The primary gas which is methane is releases directly to the atmosphere and causes global warming. Besides, using polluted water for general and daily use causes a variety of ailments, including fatigue, skin irritation, headaches, and psychological disorders in persons who live near dumping sites (Etea et al., 2021).

Leachate generation is an issue that affects every landfill throughout the world. The contamination of water by waste landfill leachate is a significant environmental impact of waste landfilling. Leachate is a contaminated liquid that drains from the bottom of solid waste disposal facilities like landfills. Its content changes greatly based on the waste's composition as well as its age. It contains a wide range of dissolved and suspended elements. Polluted leachate continues to be produced even after a municipal solid waste landfill site is closed, which can last for 30-50 years and has a significant environmental impact if released untreated into the environment (Naveen et al., 2015).

As a result, sewage and landfill leachate treatments encompass a variety of techniques for managing and disposing of solid waste's liquid components. The purpose of treatment is to lower the contaminant load so that leachate and sewage liquids can be released safely into groundwater, streams, lakes, and the ocean.

2.2 Leachate

Leachate is a by product created in landfills, incineration facilities, composting plants, and transfer stations due to physical, chemical, and biological changes in municipal solid wastes. It has a high strength and toxicity. The volume of leachate produced varies depending on the quantity of precipitation and stormwater run-on and run-off, the volume of groundwater entering the waste-containing zone, and the waste material’s moisture content and absorbent capability. Rainfall substantially impacts leachate volume and pollutant concentrations when collected through perforated pipes. Figure 2.1 shows the dark color of the leachate pond with a certain depth for the storage of the leachate and extreme rainfall events.

Figure 2. 1: Example of Leachate Pond

As illustrated in Figure 2.2, the amount of liquid originally contained in the waste and the amount of precipitation that enters the landfill via infiltration or falls directly on the waste dictate the rate of leachate production. The chemical composition of leachate will be influenced by the biological breakdown of biodegradable organic components and chemical oxidation processes. It will alter as the landfill decomposes through the various phases. These pollutants must be removed in order to prevent pollution from leachate discharge into surface watercourses and groundwater absorption. Due to the high concentration and diversity of contaminants, a single treatment system could not reach the discharge levels needed by some countries, much less eliminating the pollutants.

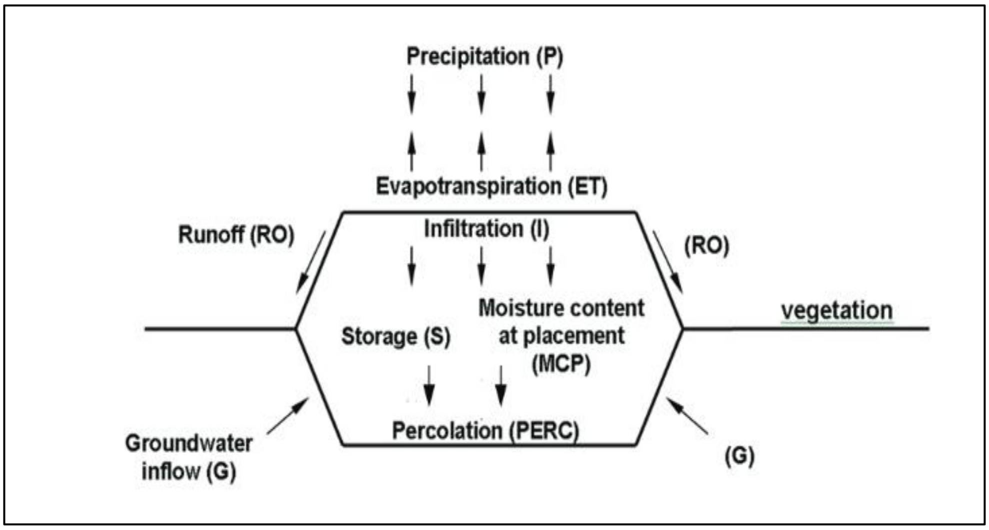

Figure 2. 2 : Leachate Generation in Landfill (Schiopu & Gavrilescu, 2010)

2.3 Leachate Characteristics

Municipal landfill leachate contains pollutants classified into four major groups: organic contaminants and substrates, inorganic compounds, heavy metals, total dissolved solids (TDS), and colour (Mojiri et al., 2021). As the number of years of landfill operation increases, the leachate characteristics will also vary in terms of the content level of dissolved organic matter, inorganic macro-components, heavy metals, and xenobiotic organic compounds (Khoo et al., 2020). Landfill leachate can be classified as young, intermediate, or old based on its age as shown in Table 2.1 (Khoo et al., 2020). Landfill leachate age can be divided into four different periods: transition (0–5 years), acid creation (5–10 years), methane fermentation (10–20 years), and final maturation (> 20 years).

Table 2. 1 : Characteristics of landfill leachate (Khoo et al., 2020)

	Type of Leachate		
	Young	Intermediate	Old
Age (years)	0 - 10	10 - 20	>20
pH	<6.5	6.5 - 7.5	>7.5

BOD_5/COD	0.5 - 1.0	0.1 - 0.5	<0.1
BOD_5 (mg/L)	>4000	1000 - 4000	<400
COD (mg/L)	>10 000	4000 - 10 000	<4000
TOC (mg/L)	>2500	1000 - 2500	<1000
N-NH_3 (mg/L)	<400	-	>400
Heavy metals	Low-medium	Low	Low
Recommended treatment	Biological	-	Physico-chemical
Composition	VFA(80%)	VFA(5-30%),HA,FA	HA and FA(80%)

Note:BOD_5: biochemical oxygen demand; COD: chemical oxygen demand; TOC: total organic carbon; VFA: volatile fatty acids; HA:humic acids and FA:fulvic acids.

According to Mojiri et al. (2021), leachate in young landfills (the acid phase) includes low pH values, high amounts of volatile acids, and simply decomposed organic debris. Leachate methane production and pH are high in mature landfills (the methanogenic phase), and the organic compounds present are primarily humic and fulvic components.

The fatty acid level in the acidogenic phase can reach up to 95 percent of the organic content, causing the pH of the leachate to drop to between 4.5 and 6.5.As the pH of leachate decreases, the solubility of many compounds, including heavy metals, increases. During the methanogenic phase, the accumulated fatty acids are digested by methanogenic bacteria and liberated as methane gas and carbon dioxide. This causes an increase in pH due to the consumption of fatty acids. Therefore, the pH for the intermediate leachate can rises from 6.5 to 7.5. Meanwhile, in the stable and mature methanogenic phase for old leachate (>20 years), pH will continue to increase from 7.5 to 9.0 (Khoo et al., 2020).

2.4 Leachate Treatment

Treatment usually entails several processes to remove the various harmful elements. For example, biological treatment can be used to minimise organic components in young leachate (which has a high biodegradability). Anaerobic, aerobic, and anammox therapies are examples of biological treatment approaches. When biological treatment procedures are no longer practical (because to limited biodegradability), physicochemical treatment methods must be used. The treatment method is chosen based on the strength of the leachate (Khoo et al., 2020). The landfill leachate contains colloidal particles, dissolved solids, and organic materials. These pollutants are physically small and have the same surface layer charge in the aqueous medium. As a result, bringing the particles closer together and forming a heavier mass for settling to attain water purity becomes more difficult. Therefore, coagulation and flocculation are the most popular classical physicochemical treatments for solid-liquid separation. Apart from that, extensive research has focused on improved and enhanced coagulation–flocculation, clarification, and biological processes (aerated lagoons, activated sludge, anaerobic filters, stabilisation ponds, upflow anaerobic sludge blanket, sequence biological reactor, rotating biological contactors, and nitrification or denitrification processes). This is because it can be considered as potential leachate treatment scenarios, owing to their reliability, simplicity, high cost-effectiveness, and reduction of stabilization time and acceleration of biogas production. Table 2.2 shows various types of landfill leachate treatment.

Table 2. 2 : Various types of landfill leachate treatment

Treatment	Key Findings	Removal	Reference
Coagulation-flocculation	Simple technique and easy to operate. The removal mechanism is mainly based on charge neutralization of negatively charged colloids by cationic hydrolysis products, followed by the combination of impurities in an amorphous hydroxide precipitate via flocculation matter.	Non-biodegradable organic compounds, suspended solids, colloidal particles, turbidity, color, and heavy metals	(Tunc, 2020)
Adsorption/Photo Fenton Ozone	Using sawdust as activated carbon material to be applied in adsorption process as pre-treatment of solar photo-Fenton and solar photo-Fenton + O_3.	Ammonia, COD, and color	(Poblete & Pérez, 2020)
Biological treatment	Aerobic technique utilizes oxygen (O_2) and aerobic microbes to degrade organic compounds into carbon dioxide (CO_2)	Organic pollutants	(Siddiqi et al., 2022)

	gas. Aerobic treatment is cheap and effective for young leachate and ensures the removal of nitrogen from old leachate through the process of nitrification and denitrification.		
Chemical Precipitation	Low implementation cost. The leachate first treat with combining chemical precipitation with biomass ash and then followed by bioremediation through microalgae.	Color, COD, BOD5, Kjeldahl nitrogen, total phosphorus, total chlorine, total solids, total suspended solids, total phenolic content, and mineral composition	(Viegas et al., 2021)
Electrocoagulation	Using iron as electrodes. Electrocoagulation reduced sludge production as compared to chemical coagulation, no requirement for external chemical coagulants, ease of operation,	COD, color	(Huda et al., 2017)

	short operating time, and low capital and operating costs.		
a) Electro-ozonation / adsorbent augmented SBR b) Anaerobic Sequencing Batch Biofilm Reactor	At first stage, the raw concentrated leachate was treated by electro-ozonation reactor. The electro-ozone reactor was reinforced by a cross-column ozone chamber to develop ozone gas diffusion. Furthermore, the ozone reactor was supported with anode and cathode plates (Ti/RuO_2–IrO_2, 18 cm × 8 cm). After that leachate was moved to the second reactor (SBR + Composite adsorbent). Biomass from the bottom of a landfill leachate stabilisation pond was immobilized in polyurethane foam cubes	COD, color and nickel (Ni) COD	(Mojiri et al., 2021)

	as inoculum.		
Coagulation-flocculation using natural coagulant	Guar gum is used as natural coagulant in leachate treatment. Guar gum floc formed is compact and well-structured. Energy-dispersive-x-ray analysis showed that guar gum was capable to adsorb multiple ions from the leachate.	COD	(Cheng et al., 2020)

2.5 Coagulation

Coagulation is the process by which charged suspended particles in water are neutralised. Coagulants, or positively charged substances, are generally introduced to the process to neutralise charge because natural particles are typically negative. Table 2.3 shows various types of coagulant used to treat leachate. Most of the research use natural coagulant and artificial coagulant to treat the leachate as it gives better removal of turbidity and other contaminants (Ugwu et al., 2017). Coagulants clump together suspended particles by changing their electrical charge. To accomplish good coagulation and microfloc production, a high-energy, rapid-mix is required to appropriately spread the coagulant and enhance particle collisions (Coagulation and Flocculation & Process Fundamentals, 2015). Overmixing has little effect on coagulation, whereas inadequate mixing leaves this phase unfinished. The ideal contact time in a rapid-mix chamber is 1 to 3 minutes (Coagulation and Flocculation & Process Fundamentals, 2015). Colloidal particles with the same charge resist each other in the same way that magnets do. Water clarity is reduced as millions of particles repel one other. The neutralisation of electrical charge allows particles to cluster together and form flocs. The clumped particles can now be filtered out of the water. The greater the flocs of particles, however, the easier it is to filter them (Coagulation and Flocculation in Water Treatment:Metering Pumps and Mixers, 2018).

Table 2. 3 : Various types of coagulant used in leachate treatment

Coagulant	Key Findings	Reference
Tannin (Organo-floc)	Less sludge produced. Low molecular weight cationic vegetable-based organic polymer. Because most colloidal particles in water are negatively charged, tannin extract is frequently chemically modified by adding positively charged groups to the tannin matrix, a process known as cationisation.	(Ibrahim & Yaser, 2019)
Bio-coagulant (Opuntia ficus mucilage)	Highest removal of COD compared to $FeCI_3$ and Polyamine-Polyacrylamide.	(Martínez-Cruz et al., 2021)
Ferric Chloride ($FeCl_3$)	Optimal conditions determined by the model were: 4.4 g/L of $FeCl_3$ and 9.9mL/L of flocculant. Removal efficiencies reached: 89±6, 69±4.8, 94±1.3, 80±8.7 and 89±1.2% for phenol, turbidity, color, COD and absorbance at 254nm (Abs 254nm) respectively.	(Bakraouy et al., 2017)
Zirconium($ZrCI_4$)	ZrCl4 was better than the traditional coagulants ($FeCl_3$ and $AlCl_3$) for dissolved organic matter (DOM) removal. The efficient DOM removal performance of	(Hao et al., 2022)

	$ZrCl_4$ under optimal dosage of 5.0 mM and initial pH of 6.0.	
Ferric chloride($FeCI_3$)	Optimum coagulant dose of 12 gFe3+.L−1 removed 50%, 89.9%, and 80% of COD, turbidity and color.	(Chaouki et al., 2021)
Alum	At an alum dose of 750 mgL1, a pH of 8.5, and a mixing speed of 100 rpm, 54% of COD is removed.	(Cheng et al., 2021)

2.5.1 Coagulants

This study uses Tween80 (Polysorbate 80) as coagulants to determine the percentage removal of parameters in jar testing. Tween80 is a common surfactant micelle. The surfactant molecule is depicted in Figure 2.3. Surfactants (surface active agents) are amphiphilic compounds that include two different groups: a hydrophilic group and a lipophilic group (Anestopoulos et al., 2020). In general, surfactants can be divided into cationic, anionic and nonionic according to the chemical property of the hydrophilic head parts (International Products, 2022).They are molecules that generally modify the energy interactions at interfaces, typically via changing the surface or interfacial tension.

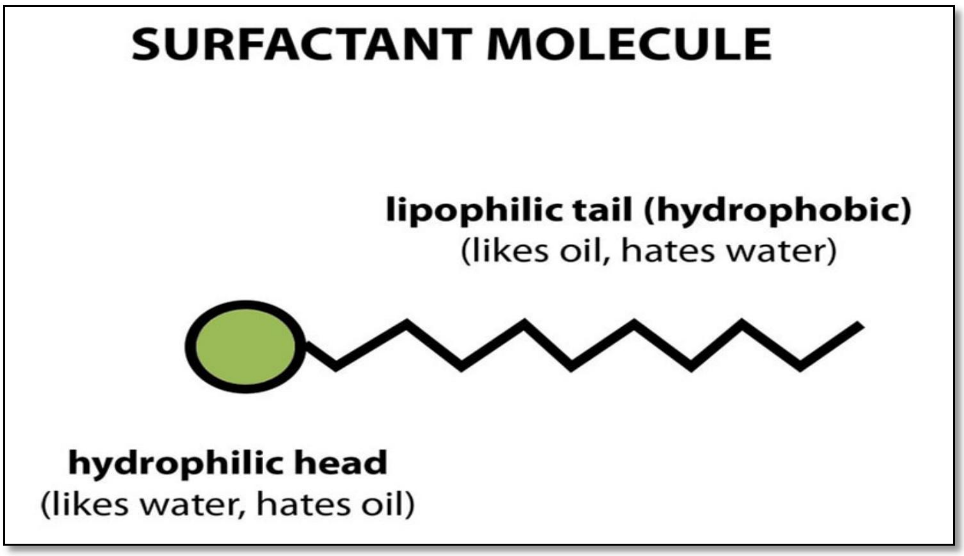

Figure 2. 3 : Surfactant Molecule

2.6 Flocculation

The particle size is increased from submicroscopic microfloc to visible suspended particles via flocculation (Stechemesser & Dobiáš, 2005). This suspension of particles is referred to as "floc." As it settles, the floc congregates with the colloidal particles. In addition, the floc is positively charged, whereas the colloidal particles are negatively charged. As a result, the flocs attract and settle colloidal particles. Figure 2.4 depicts flocs growing to a size that can be removed by sedimentation and filtering (Flocculation, n.d.).

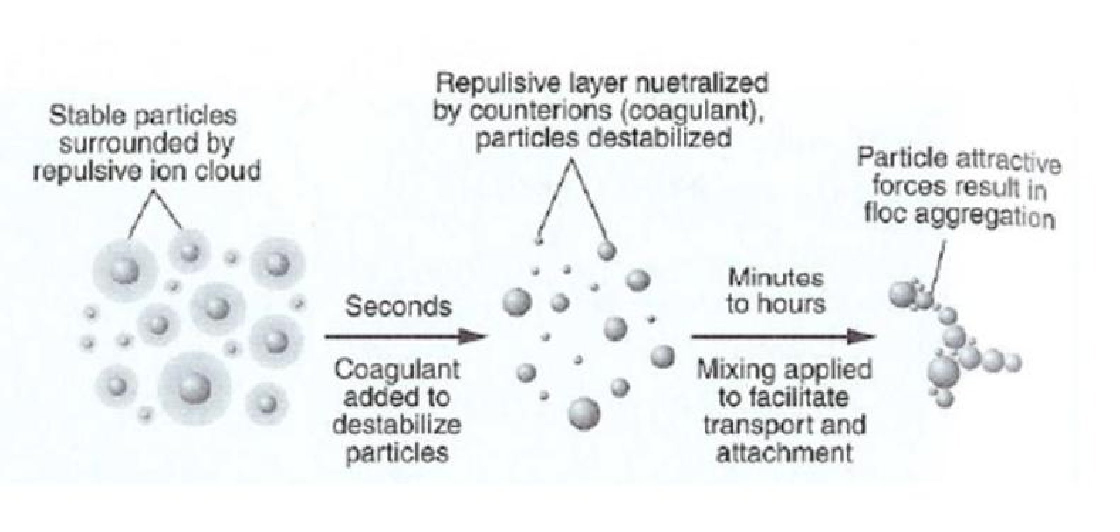

Figure 2. 4 : Growth of flocs to a size that can be removed by sedimentation and filtration (Flocculation, n.d.)

The adhesion and contact process in which dispersion particles form larger clusters is known as flocculation (Corrosionpedia, 2014). Flocculants can be applied alone or in combination with coagulants, depends on the charge and chemical composition of wastewater. Flocculants are characterized from coagulants by the aspect that they are polymers, whereas coagulants are generally salts. They vary in molecular size (weight) and charge density (percentage of the molecule with anionic or cationic charges), which is used to "balance" the charge of the particles in water, causing particles to gather together and dewater. In general, anionic flocculants are utilised to trap mineral particles, whereas cationic flocculants can trap organic particles (ChemREADY, 2021).When an anionic flocculant reacts with a positively charged suspension, it adsorbs on the particle, causing instability through bridging or charge neutralisation. The flocculating agent is added slowly in this process to allow for interaction between the small flocs and clumping into larger particles. The freshly formed agglomerated particles are quite fragile and can be torn apart during mixing by shear forces (About Coagulation and Flocculation, 2017). It is also important to avoid overdosing on the polymer, as this produces settling and clarity issues. Because anionic polymers are lighter than water, increasing the dosage causes the floc to float rather than settle. Contact times for flocculation are designed to range from 15 to 20 minutes to an hour or more (Coagulation and Flocculation & Process Fundamentals, 2015).

2.7 Jar Test

The jar test is a common laboratory experiment for determining the optimum water or wastewater treatment operating parameters. As can be seen from Table 2.4, it shows the range of operating parameters in the jar test experiment. The speed and time for rapid mixing range from 100-250 rpm and 0.5-5 minutes, while for slow mixing, the ranging parameter is 15 - 60 rpm and 10-55 minutes.

This method allows for small-scale pH adjustments, coagulant or polymer dose variations, alternating mixing speeds, or testing of different coagulant or polymer types to predict the operation of a large-scale treatment operation. A jar test simulates the coagulation and flocculation processes, which encourage the removal of suspended colloids and organic materials, which can cause turbidity, odour, and taste issues.

Table 2. 4 : Range of operating parameters obtained from literature (Cheng et al., 2020)

Operating parameter	Range
Speed of rapid mixing (rpm)	100 – 250
Duration of rapid mixing (min)	0.5 – 5
Speed of slow mixing (rpm)	15 - 60
Duration of slow mixing (min)	10 - 55

Generally, there are two types of mixing, which are rapid mixing and slow mixing. The mixing speed is critical in the coagulation-flocculation process because the initial rapid mixing stage guarantees that the coagulant is evenly dispersed throughout the suspension, while slow mixing keeps the particles suspended so that there are collisions between the particles (Zhang et al., 2013). Flocs breakage happens at higher mixing speeds as the flocs formation is destroyed by surface erosion. Apart from that, for slow mixing conditions, researchers discovered that slow mixing has a substantial influence on the size, strength, and structure of flocs. This implies that slow mixing effects on coagulation are influenced by coagulants and coagulation processes (Zhang et al., 2013). In any conventional treatment plant, coagulant mixing is conducted in a concrete basin with a mechanical mixer, which takes around 1–2 minutes of retention time. Therefore, there are various ranges for mixing time as mechanical mixing with a prolonged retention period cannot ensure coagulant dispersion that is rapid and uniform (Ghernaout & Boucherit, 2015).

2.7.1 Parameters

Several studies regarding the leachate treatment to remove organic and inorganic matter are discussed in Table 2.6. The conventional jar test involved setting up a series of leachate samples on a special multiple paddle stirrers and dosing the samples with various coagulants and flocculants in different types of Tween80 dosage, and different pH.

pH plays an important role in the coagulation process. Thus, pH must be controlled to establish optimum condition for coagulation.For example, 3M sulphuric acid (H_2SO_4) and 3M sodium hydroxide (NaOH) were used to adjust the pH.