ORGANIC AND NUTRIENT REMOVAL OF INDUSTRIAL DISCHARGE FROM ELECTRONIC INDUSTRY

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CERTIFICATION OF APPROVAL

Organic and Nutrient Removal of Industrial Discharge from Electronic Industry

by

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

NUR NABILAH HIDAYAH BINTI ISMAIL

ABSTRACT

Electronic wastewater has recently become an emerging issue with the development of electronic production. Currently, wastewater generated from the production of electronic components are being treated using a chemical treatment system. However, the production wastewater has shown an excessive amount of organic and nutrient compound that exceed the DOE standard discharge limit. The objective of this study is to investigate the effectiveness of different jar test regime using coagulants such as Aluminum Sulfate, Ferric Chloride (FeCl), Alum-Lime coagulant, and Alum-Ferric Coagulant in removing organic and nitrogen compound from the industrial discharge of semiconductor industry and to determine the optimum dosage and pH for each coagulant using chemical precipitation method. In this study, test was conducted using chemical precipitation of aluminium sulphate, ferric chloride, alum-lime coagulant, and alum-ferric chloride coagulant was determined as the mechanism underpinning the removal of organics and nutrients in wastewater. Laboratory-based experiments, simulating real-world conditions, were conducted to achieve this goal, employing the jar test method to mimic the coagulation-precipitation process. The study assessed their effectiveness in removing contaminants such as Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), Ammonia, Nitrate, Total Phosphorus, and Turbidity. In each experimental run, one-liter samples of wastewater were placed in six separate jars. The dosage of the coagulant and pH of the wastewater samples were varied across the jars to explore different treatment conditions. The results obtained from the jar test experiment of the wastewater indicated that the effluent fell short of meeting the Department of Environment (DOE) Standard B criteria, except for COD and phosphorus. The highest removal percentages for COD, TSS, turbidity, ammonia, nitrate, and total phosphorus were achieved with a pH of 10 and an alum dosage of 500 mg/L, with removal percentages of 82.9%, 85.4%, 97.9%, 85.7%, 87.5%, and 56.7%, respectively. For the alum-lime coagulant, the removal percentages with a pH of 10, alum dosage of 500 mg/L, and an additional lime dosage of 200 mg/L were 72.9%, 90.3%, 99.4%, 77.4%, 95.3%, and 51.1% for COD, TSS, turbidity, ammonia, nitrate, and total phosphorus, respectively.

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CHAPTER 1
INTRODUCTION

This chapter presents the framework of the research study. It introduces the project background, electronic wastewater characteristic. This section enlightens in detail the problem statement, objectives followed by the scope of the study.

1.1 Project Background

The growing demand for electronic products worldwide in recent years has made Malaysia’s electronic industry one of the most important drivers of the country's economy. The electronics sector is the largest in the manufacturing industry, accounting for approximately 4.9 percent of Malaysia's GDP in 2022. From 2021 to 2022, Malaysia manufactured three billion more semiconductors than the previous year. In the meantime, the nation produced the most integrated circuits in the past ten years in 2022, setting a record of 55 billion units (Statista, 2023). Nonetheless, the rapid development of the electronic sector poses environmental risks such as wastewater creation and excessive consumption of clean water (Chin et al., 2019). Electronic wastewater contains extremely toxic cyanide (CN), heavy metal ions, oils and greases, organic solvents, and a complex effluent composition, as well as biological oxygen demand (BOD), chemical oxygen demand (COD), Suspended Solid (SS), and turbidity (Rajoria et al., 2022).

This study examines the generation of wastewater from the electronic industry in Perak, that will be treated using a chemical precipitation method. The company currently manufactures power inductors, EMI suppression filters, and a variety of other products. The wastewater production has revealed an excess of organic and nutrient content that might potentially be recovered. Chemical precipitation has demonstrated a significant potential for recovering organic and nutrient compounds with a simple setup, making it an attractive option for use.

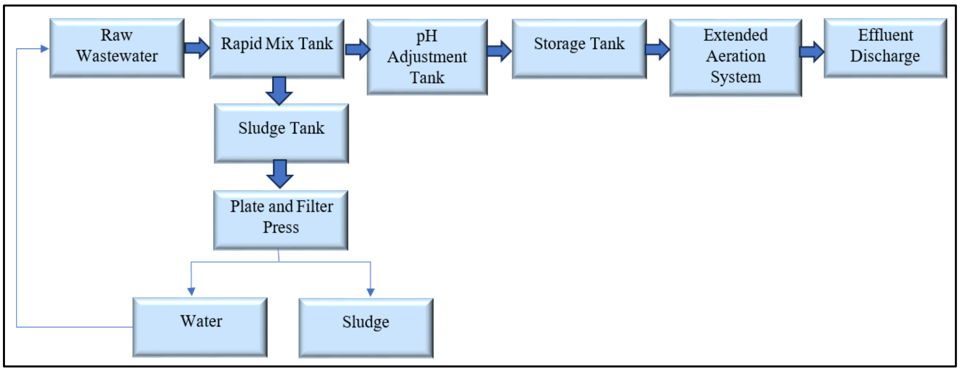


Figure 1: Schematic Diagram of Treatment Plant

According to the company process, wastewater is generated into two streams: one for concentrated wastewater (concentration of heavy metals above 1000 mg/L) and another for non-concentrated wastewater (concentration of heavy metals below 1000 mg/L). These two wastewater streams are discharging heavy metals, organic and nutrient. Two of Cosmotec's evaporator units will be used in the concentrated stream treatment process. The system that uses high temperatures to evaporate wastewater was fed with concentrated wastewater. The pressure, temperature, concentration, and total amount of wastewater that evaporates are all monitored by the electronically controlled Cosmotech evaporator. In a single batch, about 150,860.5 litres of wastewater were evaporated. The concentrated wastewater was kept in a tank after the evaporation process before being disposed of by a contractor. After condensing, the concentrate's vapour was moved to the effluent treatment system (ETS). The untreated non-concentrated wastewater stream (below 1000 mg/L of heavy metals) from the process was stored in several storage tanks.

The ETS consists of a chemical precipitation system comprising a storage tank, a pH adjustment tank, and a rapid mix tank. After adjusting the pH, the wastewater is discharged into the drainage system. Although the Department of Environment's permit allows for a maximum treatment capacity of 15 m^3 per day, the rapid mix tank can only handle 5 m^3 per batch. Both wastewater streams then undergo two stages: rapid mix (coagulation) and slow mix (flocculation). To prepare the effluent for chemical precipitation, the pH is adjusted to 10, a level recommended by the supplier to ensure the removal of all heavy metals in accordance with required effluent discharge standards, as each metal has a different optimal pH value according to its solubility curve. Subsequently, the effluent undergoes a sedimentation process, all within the same tank. The resulting sludge from this process is transferred to a sludge tank, where polymer (Ferric Chloride) is added as a chemical coagulant. Afterward, the sludge is passed through a plate and frame filter press to remove excess water, and the final sludge is preserved for disposal. The wastewater is then transferred to a pH adjustment tank for pH correction before being stored in the storage tank. Both wastewater streams undergo treatment using a biological treatment system (Extended Aeration System) to meet Department of Environment standards before disposal. Since the resulting sludge contains heavy metals, it undergoes treatment before disposal. Table 1 illustrates the wastewater from different areas in process units that exceed the limits set by DOE standard B.

Table 1:Wastewater from different areas in process units that exceed limits ruled by DOE standard B

Area	Parameters	Value	Limit	Flow Discharge
Evaporator Area	COD	26,000.0 mg/L	200.0 mg/L	2.9 m^3/hr
	BOD	2,200.0 mg/L	50.0 mg/L	
	TSS	360.0 mg/L	100.0 mg/L	
	Sulphide	772.0 mg/L	0.5 mg/L	
	Formaldehyde	11.1 mg/L	2.0 mg/L	
	Color	244 ADMI	200 ADMI	
Weekly holding tank SMC	COD	1,100.0 mg/L	200.0 mg/L	
	BOD	360.0 mg/L	50.0 mg/L	
	Sulphide	7.5 mg/L	0.5 mg/L	
	Formaldehyde	10.4 mg/L	2.0 mg/L	
F-Plate FMC	pH	9.2	5.5 – 9.0	
1st bath F-Plate FMC	pH	13.2	5.5 – 9.0	
	COD	4,400.0 mg/L	200.0 mg/L	
	TSS	280.0 mg/L	100.0 mg/L	
	Sulphide	49.0 mg/L	0.5 mg/L	
DLW43 Plating	pH	4.9	5.5 – 9.0	
	COD	610.0 mg/L	200.0 mg/L	
	BOD	350.0 mg/L	50.0 mg/L	
	Sulphide	3.7 mg/L	0.5 mg/L	

1.2 Problem Statement

Currently, wastewater generated from the production of electrical components is being treated using a chemical treatment system, followed by an extended aeration activated sludge system in the Effluent Treatment System (ETS). The inorganic coagulant Ferric Chloride (FeCl) is commonly used in this electronic industry to remove organic matter, nutrients, and heavy metals from ETS. However, the ETS in electrical production has shown an excessive amount of organic and nutrient compounds that could potentially be recovered. Hence, this study seeks to optimize the dosages of the chemical treatment system with different types of coagulants to meet the effluent discharge limits set by the Malaysian Environmental Quality (Industrial Effluents) Regulations, 2009.

1.3 Objective

The objectives of this study are outlined as below:

1. To investigate the effectiveness of different jar test regime using coagulants such as Aluminum Sulfate ($Al_2(SO_4)_3$), Ferric Chloride (FeCl), Alum-Lime coagulant, and Alum-Ferric Coagulant in removing organic and nitrogen compound from the industrial discharge of semiconductor industry.
2. To determine the optimum dosage and pH for the removal of organic and nutrient compounds in the wastewater treatment system using chemical precipitation method.

1.4 Scope of Study

The scope of this study includes:

1.4.1 Sample Characterization

- i. The wastewater will be taken directly from semiconductor company and treated using Jar Test for Optimum pH and Optimum dosage with different coagulant. This method will be performed on a lab scale, with 1000 ml of wastewater.
- ii. Wastewater generated from semiconductor company were characterized and analysed in accordance with APHA methods.
- iii. Sampling Parameters conducted throughout the study include Ammonia-Nitrogen, Nitrate-Nitrogen, Total Phosphorus, COD, TSS, turbidity, and pH.
- iv. Wastewater samples from the study will be measured in triplicates to ensure results consistency.

1.4.2 Jar Test Experiment

- i. The wastewater will undergo treatment using the 8-Jar Test to determine the optimum pH and dosage with different coagulants:

Aluminum Sulfate, Ferric Chloride, Alum-Lime, and Alum-Ferric Coagulant.

ii. This method will be conducted on a laboratory scale using 1000 ml of wastewater.

iii. Wastewater generated from the chemical precipitation method will be characterized and analyzed in accordance with APHA methods.

iv. Sampling parameters conducted throughout the study will include Ammonia-Nitrogen, Nitrate-Nitrogen, Total Phosphorus, COD, TSS, and Turbidity.

v. Wastewater samples from the study will be measured in triplicate to ensure consistent results.

CHAPTER 2

LITERATURE REVIEW

This chapter presents a literature review on the different types of coagulant used involving the way to conduct the research.

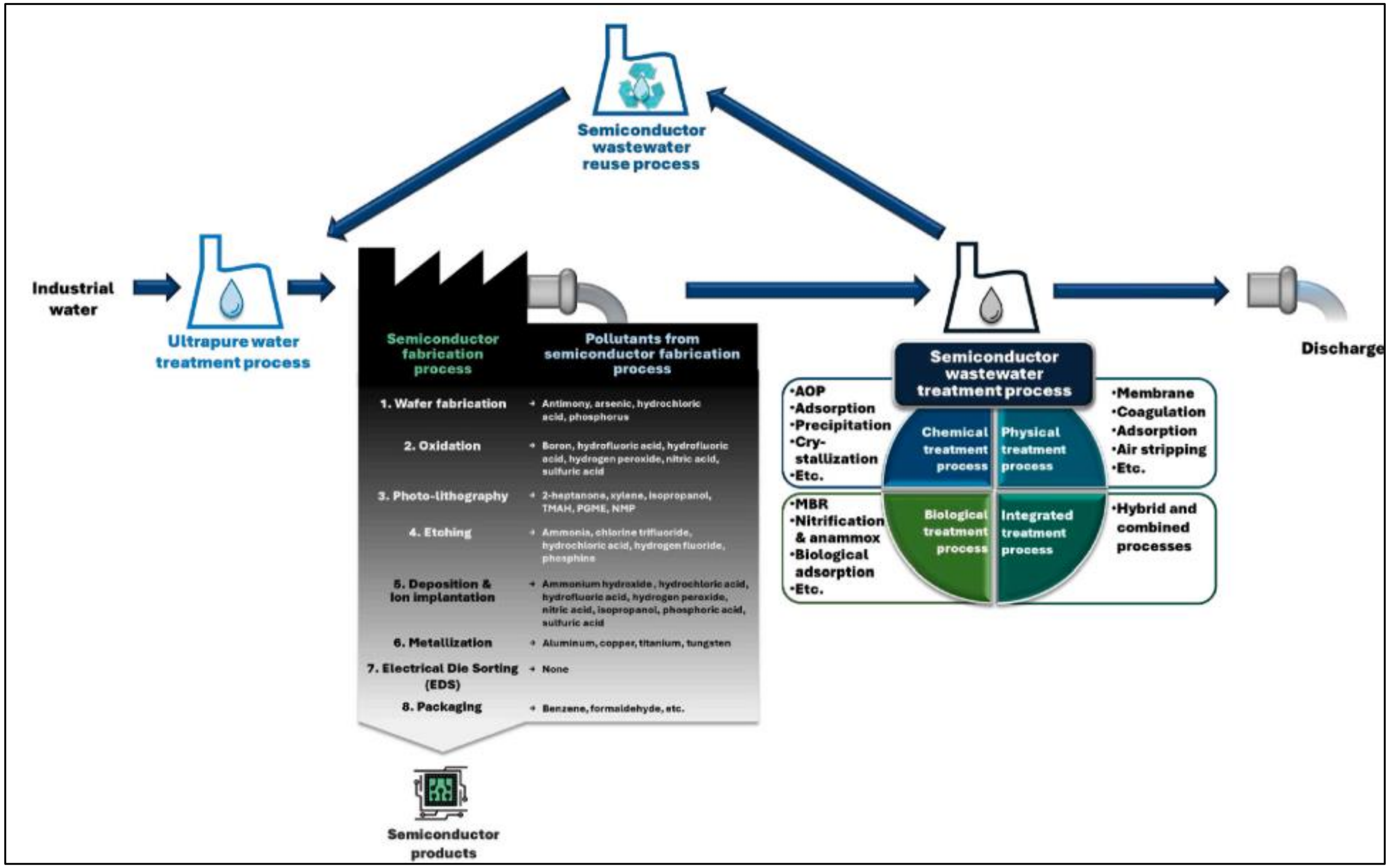
2.1 Electronic Manufacturing Process

Electronic industry are usually design, manufacture, and supply of electronic components, particularly ceramic capacitors, as well as other electronic components like inductors, resistors, sensors, and more. A multilayer ceramic capacitor is completed as a chip, mainly through the following eight forming processes such as printing of the internal electrodes on the dielectric sheet, stacking of the dielectric sheets, pressing process, cutting process, sintering process, applying and baking the outer electrodes, plating process, and measurement, and packaging process.

A ceramic capacitor functions as a fixed-value capacitor, with the ceramic material serving as the dielectric. Among these, multilayer ceramic capacitors (MLCCs) are the most commonly manufactured and employed capacitors in electronic devices, with an estimated production of approximately one trillion pieces annually (Ho et al, 2010). Ceramic capacitors are also utilized in specialized configurations for various purposes, such as RFI/EMI suppression, feed-through applications, and in larger sizes as power capacitors for transmitters.

Fabrication processes of multilayer ceramic capacitor chips starting from printing of internal electrodes onto dielectric sheets. The dielectric sheets, which have been made into rolls, are coated with a metal paste that will become the internal electrodes. In recent years, nickel has been the principal metal used for the internal electrodes of multilayer ceramic capacitors, and in the case of such capacitors, the dielectric sheets are coated with a nickel paste. After the dielectric sheets have been coated with the internal electrode paste, the sheets are stacked in layers, one on top of the other. Pressure is applied to the stacked layers of the dielectric sheets to crimp and form them. As a rule, the processes so far are undertaken in a clean room to keep the materials free from foreign matter. After that, the blocks of the stacked dielectric are cut to dimensions of 1.0 mm × 0.5 mm, 1.6 mm × 0.8 mm or any other specific chip size.

Then, the cut chips are fired at a temperature in the range of 1000 to 1300 degrees Celsius. The ceramic and internal electrodes are made into an integrated whole as a result. The two ends of the fired chips are coated with a metal paste that will become the external electrodes. If nickel is used for the internal electrodes, a copper paste is applied, and the chips are baked at a temperature of around 800 degrees Celsius. After the external electrodes have been baked, one layer of nickel and one layer of tin are plated onto their surfaces. Electrolytic plating is normally used: Nickel plating is for improving reliability and tin plating is for facilitating solder mounting. With this process, the chips are now complete. In recent years, multilayer ceramic capacitors have become increasingly smaller and their capacitance has increased while their fabrication processes have been improved; for instance, the dielectric layers have become thinner and the precision with which the layers are stacked has been enhanced (Murata, 2011). The wastewater generated from the manufacturing process needs to be treated to ensure compliance with the industrial effluent discharge limits. Table 2 below displays the industrial effluent discharge limits outlined in the Environmental Quality (Industrial Effluent) Regulations 2009.



Semiconductor fabrication process	Pollutants from semiconductor fabrication process
1. Wafer fabrication	Antimony, arsenic, hydrochloric acid, phosphorus
2. Oxidation	Boron, hydrofluoric acid, hydrofluoric acid, hydrogen peroxide, nitric acid, sulfuric acid
3. Photo-lithography	2-heptanone, xylene, isopropanol, TMAH, PGME, NMP
4. Etching	Ammonia, chlorine trifluoride, hydrochloric acid, hydrogen fluoride, phosphine
5. Deposition & Ion implantation	Ammonium hydroxide , hydrochloric acid, hydrofluoric acid, hydrogen peroxide, nitric acid, isopropanol, phosphoric acid, sulfuric acid
6. Metallization	Aluminum, copper, titanium, tungsten
7. Electrical Die Sorting (EDS)	None
8. Packaging	Benzene, formaldehyde, etc.

Figure 2: A schematic diagram summarized the electronic fabrication process, wastewater generation, treatment process and discharge.

Table 2: Standard Limit of Discharge of Industrial Effluents

Parameter	Unit	Standard	
		A	B
Temperature	℃	40	40
Biological Oxygen Demand (BOD)	mg/L	20	50
Chemical Oxygen Demand (COD)	mg/L	80	200
Total Suspended Solid (TSS)	mg/L	50	100
pH value	mg/L	6.0-9.0	5.5-9.0
Oil and Grease	-	1.0	10
Ammoniacal Nitrogen	mg/L	10	20
Formaldehyde	mg/L	1.0	2.0
Colour	ADMI	100	200
Sulphide	mg/L	0.5	0.5
Nitrate Nitrogen	mg/L	20	50
Total Phosphorus	mg/L	5	10

2.2 Wastewater from Electronic Industry

Large quantities of water are used to wash silicon chips in the electronic manufacturing process (Jinwook et al, 2014). Various chemicals and by-products including acids, bases, salts, organic solvents, heavy metals, fine suspended oxide particles, and organic compounds accumulate in the wastewater. During the manufacturing of wafers, hydrochloric acid gas is employed to extract silicon (Si), the primary material for wafers, while gallium arsenide (GaAs) can serve as a substitute for silicon. Consequently, polishing of wafers becomes imperative to improve their quality. Following wafer polishing, various solutions such as hydrochloric acid (HCl), hydrogen peroxide (H_2O_2), sulfuric acid (H_2SO_4), 5% sodium hypochlorite (NaOCl), ethoxylated amine, and ammonium hydroxide (NH_2OH) are utilized to eliminate contaminants from the wafer surface (KOSHA, 2020). In the oxidation process, washing solutions like SC-1 (comprising NH4OH, H_2O_2, and H_2O), SC-2 (comprising HCl, H_2O_2, and H_2O), and HF solutions are employed to remove impurities subsequent to the generation of silicon dioxide (SiO2) (Sparacin et al., 2005).

Common macromolecule resins utilized in the photoresist process include xylene (C_8H_{10}), Novolak resin, aromatic compounds, and organic solvents (Kim et al., 2011). Additionally, tetramethylammonium hydroxide (TMAH), aliphatic compounds such as ethyl 3-ethoxypropionate ($C_7H_{14}O_3$), gamma-butyrolactone ($C_4H_6O_2$), and n-methyl-2-pyrrolidone (C_5H_9NO) are frequently employed (Den et al., 2002; Jang et al., 2019; Samsung, 2015b). Furthermore, an adhesion promoter is applied to enhance the bonding between the wafer and photoresist, with hexamethyldisilazane (HMDS, $C_6H_{19}NSi_2$) being the predominant choice. (Park et al., 2011).

The etching process can be categorized into dry and wet procedures. Dry etching involves the use of gaseous compounds such as ammonia (NH_3), argon (Ar), chlorine (Cl), hydrogen (H), sulfur hexafluoride (SF_6), and fluoroform (CHF_3). On the other hand, wet etching utilizes compounds including acetic acid (CH_3COOH), ammonium fluoride (NH_4F), ammonium hydroxide (NH_4OH), hydrochloric acid (HCl), hydrofluoric acid (HF), nitric acid (HNO_3), hydrogen peroxide (H_2O_2), and isopropyl alcohol (IPA, C_3H_8O). Following etching, sulfuric acid (H2SO4) is employed to remove the photoresist. In subsequent iterations of circuit creation, oxides such as silicon dioxide (SiO2) and metals like copper (Cu), cerium (Ce), tungsten (W), and aluminum (Al) are utilized as a slurry to chemically polish the wafer in the Chemical Mechanical Polishing (CMP) process (Sim et al., 2023).

The deposition processes are divided into CVD and PVD. In CVD, main compounds like dichlorosilane (Cl_2H_2Si), nitrogen trifluoride (F_3N), nitrous oxide (N_2O), ozone (O_3), phosphine (PH_3), and silane (SiH_4) are utilized, while gaseous compounds such as hydrogen (H_2), hydrochloric acid (HCl), and hydrogen fluoride (HF) are employed in PVD (Kim et al., 2011; KOSHA, 2020). Furthermore, in the metallization process, metals including aluminum (Al), copper

(Cu), titanium (Ti), and tungsten (W) are utilized for connecting the wafers to circuits (El-Kareh and Hutter, 2012; Samsung, 2015d; Seeger, 2013). Finally, during the packaging process, semiconductor products are assembled using benzene (C_6H_6) or formaldehyde (CH_2O) (Kim et al., 2011; KOSHA, 2020).

One pollutant of main concern is the ammonia from the ammonium hydroxide which is used in the chemical mechanical polishing process. Treatment procedures for the electronic industry wastewater may include precipitation, coagulation, sludge dewatering, sedimentation, skimming, activated sludge process, filtering, or membrane separation depending upon wastewater streams, softening, demineralization, activated carbon process, cooling towers, ultra-filtration process, reverse osmosis and many more. However, the treatment of wastewater generated from electronic industries has gained much attention from semiconductor manufacturers as they work to comply with the requirements of industrial effluent treatment.

2.3 Electronic Wastewater Characteristics

Extreme amounts of ammonium (NH4) and phosphate (PO4) were reported in the semiconductor wastewater (Ryu et al. 2012a, b). The fluoride compound in semiconductor wastewater was discovered to range from 250 to 1500 mg L−1 and was generated from the etching process involved in the integrated circuit chip fabrication (Liu and Liu 2016; Lacson et al. 2021). The wastewater generated from the microelectronics process has less organic matter content, such as phosphoric acid, organic solvents, and NH4OH (Bang et al. 2016). These pollutants are generated using raw substances during manufacturing, including subprocesses (such as cleaning), wet etching, photolithography, backgrinding, and dicing (Innocenzi et al. 2022). Tetramethylammonium hydroxide (TMAH, C4H13NO) is among the chemical substances with highly problematic compounds generated by photolithography (Chung et al. 2020a, b). Diluted backgrinding wastewater (DBGW) generated from the backgrinding process is characterised by alkaline pH, NH3–N, and high colour saturation (Yang et al. 2012). Chemical mechanical polishing wastewater (CMPW) is the waste generated by the chemical mechanical polishing process (CMP). The surface of the semiconductor is made smooth and uniform by applying a mixture of abrasives like SiO2, Al2O3, or CeO2 alongside the chemical oxidation process, which exerts a downward force on the slurry (Fatehah et al. 2013).

Each process produces a different type of wastewater with different characteristics. It is challenging to provide an accurate composition of the microelectronic effluent. The first step used in the treatment of microelectronics is focusing on separating the wastewater based on the source. Based on the previous studies, microelectronic wastewater greatly differs from another industrial wastewater. These wastewaters contain between 0.34 and 3.35 mM of perfluorooctanoic acid (PFOA) in wastewater generated from the emulsifying process in fluoropolymer manufacturing, and between 5 and 60 g/L of TMAH, 5 and 66 g/L of glycerol, 50–2000 mg/L of pyrazole, 100–200 mg/L of acetone, 700–800 mg/L of calcium fluoride (CaF2), 50–1000 mg/L of KOH, NH3–N 2.8–3.9 mg/L, turbidity (NTU) 1044–6390, with pH ranging from 6.3 to 9.8, 0.1–5.3 g/L of total solid, 0–0.2 mg/L of suspended solid, 175–5000 mg/L of COD, BOD/COD between 0.11 and 0.15, 45.6–58.2 mg/L of sulphates, 65.38–72.58 mg/L of total Kjeldhal nitrogen (Omar et al. 2013; Post et al. 2012; Chowdhury et al. 2014; Wang et al. 2022; Teow et al. 2022). The main pollutants of organic solvent particles range from nano- to micro-sized (Omar et al. 2013). The contaminants are available in very low concentrations. However, it is a complex material that is difficult to degrade and eliminate using traditional treatment methods.

2.4 Chemical Precipitation Process

A common practice widely used amongst semiconductor manufacturers includes coagulation-flocculation, the process of neutralizing the ion and particle surface charge (Omar et al., 2008). Through the use of natural or chemical-based coagulants, the suspended particles are aggregated by destabilizing the particle charge. The aggregated particles then form dense flocs, which can be separated from the wastewater to produce treated water (Yeit et al, 2022). The waste contribution of the microelectronics industry, leading to adverse environmental pollution through the production of huge quantities of wastewater containing fluoride, phosphate, and heavy metals, is apprehensive (Noman et al, 2024). Table 1 summarises the physicochemical characteristics of microelectronic wastewater reported from different studies. Chemical precipitation has long been used as a pre-treatment to improve subsequent biological treatments, which can include the treatment of electronic wastewater. Coagulation is the destabilization of colloids by addition of chemical to neutralize the negative charges by rapid mixing. Coagulants can be used to reduce the electrostatic repulsive forces. The electrostatic repulsion reduced by the addition of counter charged ions. Jar test is the laboratory procedure to determine th optimum pH and optimum coagulant dose. The coagulation process is used to remove natural organic matter by adjusting the pH and coagulant dose to remove the greatest amount of suspended matter during the treatment process. The addition of acid is used to achieve the proper pH.

Flocculation is the slow mixing process that causes smaller particles to merge into larger particles that settle more easily. The particles are then more easily removed in the sedimentation and filtration process. The process of flocculation is achieved by controlling the rate of impacts between particles as they gain size. Floc size can range between 0.1 mm-3 mm. The size of the floc produced depends on which type of treatment process is utilized at a specific plant. It is important that floc has good size but also density so the floc will not shear during the sedimentation and filtration process. This process is much longer than coagulation lasting roughly 15-45 minutes.

2.4.1 Optimum pH and Optimum Dosage

The optimum pH can be determined by conducting the jar test with raw water samples, typically using six jars. The pH is adjusted during mixing using sulfuric acid (H_2SO_4) and sodium hydroxide (NaOH). The same dose of the selected coagulant will be added to each jar, followed by rapid mixing for one minute at 150 rpm to disperse the coagulant throughout the container. Then, the stirring speed will be reduced to 30 rpm, and mixing will continue for 15 to 20 minutes. This slower mixing speed promotes floc formation by enhancing particle collisions, leading to larger flocs. The mixer is then turned off, and the flocs are allowed to settle for 30 to 45 minutes. The optimum pH can be determined by plotting the residual turbidity against the pH; the lowest residual turbidity indicates the optimum coagulant pH. Similarly, the optimum dosage can be determined by adjusting the pH in all jar tests using the previously determined optimum pH and adding different doses of coagulant to each jar, following a procedure similar to the previous experiment. A graph of residual turbidity vs. coagulant dose is plotted, and the lowest residual turbidity indicates the optimum coagulant dosage (Lokesh, 2016).

Table 3: Optimum Ph and Optimum Dosage

Water Source	Initial Concentration of Contaminant	Optimum pH and Removal Efficiencies	References
Phosphate Synthetic Water	Phosphorus: 19 mg/L	pH: 7 Phosphate removal: 84.7%	Patel et al., 2022
Synthetic Water	Phosphate: 400 mg/L	pH: 3 Phosphate removal: 85.8%	Behbahani et al, 2018
Municipal Wastewater	Total Phosphorus: 50.06 mg/L	pH: 5-7 Phosphate removal: 99.98%	Kobya et al., 2021
Synthetic Wastewater	Phosphate: 30 mg/L	pH: 5 Phosphate removal: 96%	Kuokkanen et al, 2015
Oil tanning wastewater	COD: 700 mg/L	pH: 6.74 COD removal: 89.65%	Lakshmi et al., 2013
Pulp and paper mill wastewater	COD: 490-114 mg/L TSS: 40-260 mg/L	pH: 7.58 COD removal: 87.8% TSS removal: 89.8%	Khansorthong et al, 2009

2.5 Type of Coagulant in Industry

2.5.1 Inorganic Coagulant

Numerous types of coagulants find applications in the treatment of water and wastewater. These coagulants can be categorized into chemical and nonchemical variants, which include synthetic materials and natural coagulants. Each type of coagulant possesses distinct properties characterized by positive ions that effectively capture the negatively charged organic matter responsible for water turbidity. In the context of wastewater treatment, the most commonly utilized coagulants are aluminum and iron salts. These inorganic coagulants encompass various aluminum-based compounds such as aluminum chloride, aluminum sulfate, and sodium aluminate, as well as iron-based compounds like ferrous sulfate, ferric sulfate, and ferric chloride (Bolto & Gregory, 2007). The addition of these coagulants to wastewater initiates a sequence of reactions involving hydroxyl ions (OH^-), resulting in the generation of monomeric and polynuclear species. These reactions cause the dissociation of metal salts, releasing trivalent ions that subsequently hydrate to form complex water molecules, specifically Al $(H_2O)_{63}$+ and Fe $(H_2O)_{63}$+ for aluminum and iron, respectively (Yang et al., 2016). As a consequence, water molecules (H_2O) are replaced by OH− ions, yielding soluble Al $(OH)^{2+}$ and Fe $(OH)_2$ species. This process enhances coagulation performance by enabling the strong adsorption of trivalent ions onto the negatively charged surfaces of colloids (Gupta et al., 2012).

Despite their widespread use owing to their cost-effectiveness and availability, metal-based coagulants exhibit certain limitations. These drawbacks encompass a dependence on high dosages, a requirement for specific pH conditions, susceptibility to temperature variations, and the generation of substantial sludge (Bolto & Gregory, 2007). Increase sludge production rates will affect the need of additional storage requirements. Some of these inorganic coagulants, along with their advantages and disadvantages, are presented in Table 3. Moreover, an excess of aluminum and iron in effluents poses ecological and health risks, including intestinal discomfort, abdominal colic, and spasms. Additionally, ferric-based coagulants are highly caustic and can lead to conspicuous rust-colored stains associated with chemical spills and leaks (Kyzas & Matis, 2016). Hence, there is growing interest in enhancing the performance of inorganic coagulants by incorporating polymeric organic and natural coagulants in wastewater treatment processes.

Table 4: Advantage and disadvantage of inorganic coagulants (Kyzas &Matin, 2016, Wei et al, 2018)

Coagulants	Advantages	Disadvantages
Aluminum sulfate (Alum) $Al_2 (SO_4)_3 \cdot 18H_2O$	Easy to handle and apply; most commonly used; produces less sludge than lime; most effective between pH 6.5 and 7.5	Adds dissolved solids (salts) to water; effective over a limited pH range
Sodium aluminate $Na_2Al_2O_4$	Effective in hard waters; small dosage usually needed	Often used with alum; high cost; ineffective in soft waters
Polyaluminium chloride (PAC) $Al_{13}(OH)_{20}(SO)_4Cl_{15}$	In some applications, Floc, formed is denser and faster settling than alum	Not commonly used; little full-scale data compared to other aluminum derivatives
Ferric sulfate $Fe_2(SO_4)_3$	Effective between pH 4–6 and 8.8–9.2	Adds dissolved solids (salts) to water; usually, need to add alkalinity
Ferric chloride $FeCl_3.6H_2O$	Effective between pH 4 and 11 Reduce scum in secondary treatment processes.	Adds dissolved solids (salts) to water; consumes twice as much alkalinity as alum
Ferrous sulfate $FeSO_4 \cdot 7H_2O$	Not as pH sensitive as lime	Adds dissolved solids (salts) to water; usually need to add alkalinity
Lime Ca $(OH)_2$	Commonly used; very effective; may not add salts to effluent	pH-dependent; produces large quantities of sludge; overdose can result in poor effluent quality

2.5.2 Composite coagulant

The composite coagulant is a “polymerized, compounded, multi-functional” traditional coagulant. The preparation process of composite coagulant is simple but can enhance the coagulation effect (Xu et al., 2024). The benefits of composite coagulants include low mud production, wide pH range, and less temperature dependence, which are the hot spots of current research in wastewater treatment. Zhao et al., 2011 reported that the composite coagulant prepared by red mud was environmentally and economically viable for advanced phosphorus removal in urban wastewater. Composite coagulants include inorganic-inorganic, organic–inorganic, and organic-organic composite coagulants (Abujazar et al., 2022). Among them, the inorganic-inorganic composite coagulant has lower cost and easier control of the coagulation process, and its application in practical engineering is feasible. Yang et al., 2021 reported that inorganic polymeric coagulants can aid particle surface charge neutralization and sweep flocculation due to the synergistic effects of metal ions to promote phosphorus stability. Ma et al., 2022 reported the reduction of Al and Fe residual in the treated effluent of Al/Fe-based composite coagulant. Composite coagulants of Fe salts and Al salts can promote the hydrolysis degree of metal ions to enhance the ability of the ionic layer compression, electrical neutralization, adsorption-bridging, and sweep coagulation, thereby improving the phosphorus removal effect.

2.6 Parameters Affecting Coagulation Treatment Efficiency

Numerous operational variables affect the parallel and sequential reactions observed when introducing a coagulant into wastewater. These reactions include various transportation mechanisms such as Brownian diffusion and fluid motion, which facilitate interparticle bridging and the formation of flocs. These factors collectively shape the efficiency and effectiveness of the coagulation process in wastewater treatment.

2.6.1 Effects of polymer molecular weight and charge density

The coagulation efficiency is influenced by the molecular weight (MW) and charge density (CD) of polymers, impacting interparticle bridging and electrostatic forces (Verma et al., 2012). Increasing the molecular weight enhances agglomeration and floc formation. While anionic polymer charge can hinder adsorption on unwanted surfaces, it fosters polymer chain development through mutual charge repulsion among polymer molecules (Lee et al., 2014). Charge density is typically expressed as a percentage of ionic groups, including those that are charged regardless of pH and those susceptible to charging under specific pH conditions, relative to all groups within the polymer.

2.6.2 Temperature

Temperature serves as a primary driver of chemical reactions, impacting various aspects of polymer behaviour, including viscosity, mobility, collision frequency, solubility, density, and the upward or downward movement of flocs. As a result, higher temperatures accelerate chemical reactions, while lower temperatures stabilize colloidal surfaces, reducing hydrolysis reactions (Watanabe, 2017). This can potentially hinder particle mobility, increase solubility, enhance polymer reaction rates, and subsequently result in reduced coagulation efficiency.

In a study by Joudah (2014) examining the influence of temperature on coagulant flocculation efficiency, it was found that lower temperatures led to decreased flocculation efficiency due to the breakup of larger flocs. The study revealed that better turbidity removal results were achieved as the velocity gradient increased from 10 to 20, then to 30, and finally to 40 s^{-1} (Joudah, 2014). Consequently, warmer temperatures are favoured for improved flocculation (Fitzpatrick et al., 2004).

2.6.3 Effects of Mixing Conditions

The level of coagulation effectiveness in treatment is associated with the amount of coagulant used and the conditions during mixing. This process involves two distinct mixing phases, namely rapid mixing and slow mixing, as illustrated in Figure 2. Rapid mixing follows the addition of coagulants and necessitates turbulent mixing to achieve a uniform solution (Gupta et al., 2012). Inadequate rapid mixing can result in suboptimal coagulant performance, either due to insufficient or excessive dosing. Subsequently, slow mixing follows rapid mixing, aimed at enhancing particle capture and promoting floc growth.

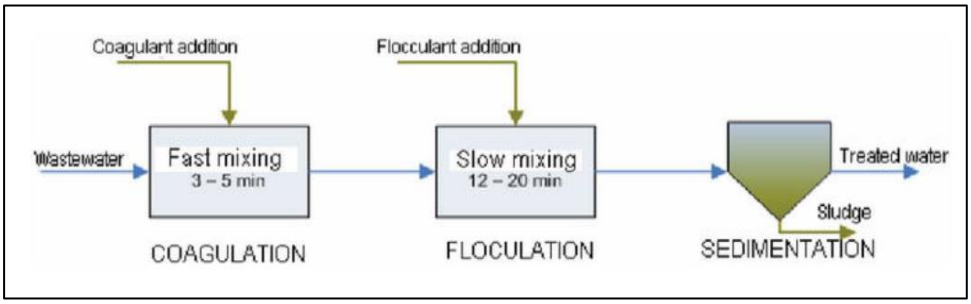


Figure 3: Schematic steps of mixing in coagulation process.

Additionally, consistent slow mixing expedites the process of floc aggregation and the entrapment of suspended particles, thereby improving their separation. During slow mixing, a velocity gradient is established for particles of similar sizes, often exceeding 1 μm. This relationship between the aggregation of a specific size and the molecular weight of the polymer can enhance the bridging or breaking forces acting on the flocs, leading them to either settle or float (Scholz, 2016). In practical terms, as depicted in Figure 2, achieving this involves initially stirring the suspension at a high rate (250 rpm) to induce floc breakage. Subsequently, slow mixing (30 rpm) is initiated to promote an increase in floc size (Rajasulochana et al., 2016). In the context of flotation principles, the need for a lower polymer dosage arises because the agitation fosters the formation of a well-established suspension composed of smaller flocs that can subsequently agglomerate and float (Wei et al., 2018).

2.6.4 Effects of pH

The pH level plays a central role in facilitating the interaction between coagulants and particles, promoting effective neutralization and the aggregation of flocs. Moreover, the solubility of metal hydroxide species is influenced by the pH range of 4 to 8 (Wei et al., 2018). Consequently, it is crucial to adjust the pH before introducing coagulants to influence the subsequent chain reactions. The specific type of inorganic coagulants or polymers, being metal-based ions, can impact floc formation by causing double-layer compression (Scholz, 2018). As the pH increases, these species acquire a charge, leading to a shift in the underlying mechanism. For example, when dealing with hydrophilic colloids like acids, pH alterations will affect protonation.

The appropriate pH will help to neutralise the negative charge colloidal particles and form linkages between colloidal particles more effectively, assisting in the formation of flocs and achieving the precipitation characteristics required (Daud et al, 2017). The highest performance in wastewater treatment is demonstrated when coagulant is used at its ideal pH level, which removes the most pollutants. According to (Nasir & Daud, 2014), the ideal range for ferric chloride is between 4 and 12. The pH range in which ferric hydroxide precipitates is between 7 and 9, with pH 8 being the minimal solubility (Daud et al, 2016).

2.6.5 Coagulant type and dosage

There are several types of coagulants utilized in wastewater treatment settings, including both inorganic options and organic polymers. Nonetheless, organic polymers generally incur higher costs than their inorganic counterparts. The cost differential hinges on the specific type and quantity of chemicals contained within the coagulant. The choice of an appropriate coagulant for wastewater treatment holds significant importance and is contingent upon factors such as water chemistry, hydrodynamics, and operational conditions within the treatment system (Wei et al., 2018).

The quantity of coagulant applied plays a pivotal role in determining how effectively metal ions interact with organic matter in wastewater to enhance its clarity. Organic polymers inherently present as highly viscous solutions, which can sometimes pose challenges in achieving uniform distribution within a medium (Bolto & Gregory, 2007). Nevertheless, they exhibit a strong affinity for particle surfaces, forming irreversible attachments. Consequently, uneven distribution of polymers within contaminated wastewater can contribute to treatment process inefficiency and increased costs (Bolto & Gregory, 2007). Hence, there is a need to increase the dosage to compensate for polymer losses.

2.7 Type of Coagulation

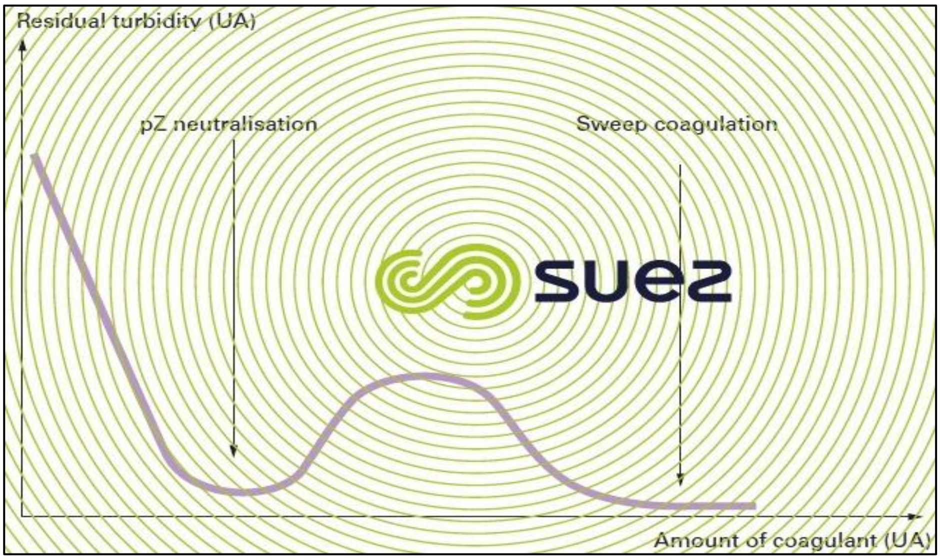


Figure 4: Graph two types of coagulation

Optimal coagulation is achieved when the point of zero charge pZ (coagulation) reaches 0, effectively removing all particles such as clay turbidity and microalgae. Using a progressively higher dosage of coagulant than what is required to neutralize the coagulation initially results in residual turbidity (depicted in Figure 4) due to charge reversal (trivalent cations shifting pZ to a positive value). This turbidity is subsequently eliminated by capturing colloids in the surplus floc, a process known as "sweep coagulation". In certain cases, this coagulation method is coupled with the use of H_2SO_4 to lower the pH, termed "enhanced coagulation", specifically employed to ensure thorough removal of organic precursors of oxidation by-products (Suez, 2023).

2.7.1 Sweep Coagulation

Sweep coagulation operates on the principle of utilizing larger flocs, which are formed during the coagulation process, to act as “sweepers” that gather and entrap smaller particles present in the wastewater. This process commences with the addition of coagulants like aluminum sulfate or ferric chloride, which induce the destabilization of colloidal particles, thereby fostering the formation of flocs. As these larger flocs traverse the wastewater, they effectively capture smaller particles, encompassing suspended solids, organic matter, and pathogens. Consequently, sweep coagulation enhances the efficiency of sedimentation and filtration processes by augmenting the size and settling rate of particles, thereby expediting their removal from the water. Undoubtedly, sweep coagulation stands as a pivotal step in the holistic wastewater treatment process, bolstering water quality before discharge or subsequent treatment phases (Yongjun, 2019).

2.7.2 Coagulation Neutralization

Coagulation neutralization emerges as a critical process aimed at adjusting the pH of wastewater to a level conducive for coagulation and subsequent treatment procedures. Often, the pH of wastewater falls outside the optimal range for coagulation, thus diminishing the efficacy of coagulant chemicals. Coagulation neutralization rectifies this discrepancy through the introduction of acid or base chemicals to modulate the pH to the desired level for effective coagulation. Acidic wastewater undergoes neutralization by incorporating alkaline chemicals such as lime (calcium hydroxide) or sodium hydroxide, while alkaline wastewater is subjected to neutralization using acidic chemicals like sulfuric acid. By fine-tuning the pH to the optimal range for coagulation, coagulation neutralization ensures that coagulant chemicals effectively destabilize particles and foster the formation of flocs. Typically performed as a preliminary step preceding coagulation and other treatment modalities in wastewater treatment plants, coagulation neutralization serves as an indispensable component in the comprehensive wastewater treatment regimen (Yongjun, 2019).

Abdel and Alseroury (2019) conducted a comprehensive chemical treatment of wastewater from one of Egypt's largest electronics factories. This treatment consisted of a sequential process that involved alkaline chlorination and chemical reduction as initial steps to eliminate cyanide and Cr^{+6} from the nickel-chrome production line's effluent. Following the pretreatment, the water was combined with effluent from all production lines and subjected to evaluation using a coagulation process. Various coagulants, such as quicklime (CaO), ferrous sulfate ($FeSO_4$), and polyelectrolyte, were tested at different compositions and concentrations. The results of the study showed that alkaline chlorination, conducted at pH 11 for 2 hours, successfully removed 100% of cyanide. During the pretreatment of nickel-chrome wastewater, hexavalent chromium (Cr^{+6}) was completely reduced to the non-toxic trivalent chromium (Cr^{+3}) form at pH 2.

Among the coagulants tested, the combination of CaO (80 mg/L) and $FeSO_4$ (60 mg/L) exhibited the highest efficiency in treating the wastewater, meeting permissible limits. This treatment led to a significant decrease in BOD and COD levels, reaching as low as 43 mg/L and 67 mg/L, respectively. Additionally, heavy metal concentrations, including Cr, Cu, Ni, and Zn, were well below 0.02 mg/L.

Mortula et al., 2020 explored the application of tertiary treatment for the remediation of organic matter, phosphorus, and turbidity in secondary effluent. To achieve their objectives, they conducted laboratory-based experiments, using the jar test as a representation of the coagulation-precipitation process. The coagulants employed in these experiments included lime, dried leaves, and polymer, while alum was used for comparative purposes. The study aimed to assess the impact of this advanced treatment on the removal of phosphorus, BOD (Biological Oxygen Demand), and turbidity. Two distinct secondary effluents originating from different wastewater treatment plants were employed to evaluate the influence of pretreatment processes on wastewater treatment performance. The laboratory-scale jar test apparatus served as a model for the coagulation-flocculation process. Each jar received one liter of wastewater sample, and varying doses of the coagulants (0, 20, 40, 60, and 80 mg/L) were introduced into the jars. The procedure included agitation at a typical rate of 300 revolutions per minute (rpm) for 2 minutes to facilitate coagulation, followed by 30 minutes of flocculation at 30 rpm, and finally, 1 hour without mixing to allow for sedimentation. The outcomes of the study indicated that the coagulation-precipitation process using different coagulants was capable of achieving phosphorus removal rates of up to 68% and BOD removal rates of up to 100%. These results were found to be comparable to those obtained using the traditional coagulant, alum, which achieved removal rates of 80% for phosphorus and 100% for BOD. Furthermore, an increase in pretreatment appeared to enhance the effectiveness of these coagulants in increasing phosphorus removal from 34.5% to 48% and BOD removal from 73.3% to 82%.

Ho et al. (2023) studied the removal of phosphorus in semiconductor wastewater using chemical precipitation with calcium fluoride and hydroxyapatite, employing a byproduct of recycled aggregate. The results of phosphorus removal showed that pH 7 is the optimum pH for achieving 99.99% effectiveness in phosphorus removal. The effect of solution pH on the removal reactions was determined under the following conditions which are a temperature of 20°C and a stirring rate of 400 rpm. Morten et al. (2022) investigated phosphorus removal without the addition of calcium ions and found that phosphate could be precipitated by increasing the pH to 9.5. Table 23 presents the average effluent total phosphorus concentrations throughout the study period for each pH and the corresponding average total phosphorus removals. Chen et al. (2013) utilized chemical precipitation to achieve optimal results for ammonia removal from landfill leachate, obtaining over 88% removal efficiencies with initial pH 10, a contact time of 30 minutes, and a Mg/N/P molar ratio of 1:1:1.

2.8 Chemical Coagulant Used in the Wastewater

Chemical coagulation is the process of using chemically produced substances to destabilise colloidal impurities in water or wastewater. The formation of flocs as a result of charge neutralisation is known as flocculation (Hamawand, 2015). Chemical coagulation is the best method for organic removal if the coagulant dose and pH are optimised. The best results for organic removal can be obtained by increasing the coagulant dose (more than what is used for turbidity removal). Coagulant dose and pH are critical parameters in the industrial wastewater treatment process (Sahu and Chaudhary, 2013). Coagulation-flocculation is particularly useful for removing colloidal particles. The use of alum as a coagulant can result in significant organic removal. The pH of the wastewater during coagulation has a significant impact on the efficacy of coagulation for organic removal. Organic removal is significantly improved in slightly acidic conditions. The optimum pH for water with a higher organic content is shifted to slightly more acidic values (Sahu, 2019); chemical coagulation (Sahu and Chaudhari, 2014), and electrochemical treatment (Sahu and Chaudhari, 2015).

2.8.1 Lime as Coagulant

High-pH chemical precipitation (lime based) has shown effective removal of the following when applied to urban wastewater and cheese production wastewater: microorganisms (60-100%), BOD5 (biochemical oxygen demand), COD (chemical oxygen demand), total suspended solids (75-91%) and total phosphorous (71-93%), temporary hardness, and high molecular weight organic compounds (humic and fulvic acids) (Carvalho et al., 2012; Prazeres et al., 2016; Semerjian et al., 2003).

Lime is the generic term used to describe hydrated lime and quicklime. Calcium hydroxide (hydrated lime) and calcium oxide (quicklime) are chemicals frequently used to raise the pH of raw water before the water is treated with alum or ferric sulphates for coagulation/flocculation. Hydrated lime and quicklime are colourless crystals or white powders that are available for purchase in bags, bulk or by truckload. Hydrated lime is commonly used by small facilities because it can be directly applied to the water treatment process. Quicklime, (in pellet form), must first be slaked, or mixed with water then heated to turn it into hydrated lime before use. Lime chemical precipitation (LCP) is a process that leads to the formation of an instantaneous and intense precipitate followed by a vigorous “sweeping” phenomenon of particles (Semerjian et al., 2003). The process is explained by the reactions that take place when lime is added to the wastewater (Prazeres et al., 2016). These reaction lead to the formation of insoluble species, such as calcium carbonate, magnesium carbonate, and magnesium hydroxide, and phosphates.

Vanerkar et al. 2013 treated food industry wastewater using coagulation and flocculation process and discussed the behaviour of coagulant supplemented with polyelectrolytes. Different coagulants and flocculants were tried to attain the best results and lime was selected as the optimum coagulant based on the cost factor. Lime was used for the coagulation and resulted in 53.59% COD and 57.19% BOD reductions respectively, at the dosage of 200 mg/L. Only, 25 mL/L of sludge was developed at this dose of the coagulant. Nazire and İkizoğlu (2017) evaluated the removal of nutrient by chemical post treatment with lime following the biological stage. Lime was added to the supernatant and pH was increased to 10.5. The result shows that ammonia nitrogen was removed by air stripping, and removal of phosphate was achieved with chemical precipitation. Lime dosage optimisation resulted in an optimal treatment pH of 9. A study conducted to improve primary treatment of urban wastewater with lime-induced coagulation. Lime addition up to pH 9 had increase the COD removal rate in the primary treatment from typical 30-35% of plain sedimentation up to 55- 70% (Marani et al, 2004).

2.8.2 Aluminum Sulfate as Coagulant

Coagulation process using alum as coagulant is evaluated in treatment of municipal wastewater on the basis of organic material. A series of jar test experiments was run at 100 rpm for 1 min, 30 rpm for 20 min and 30 min for settling. 150 mg/l and 450 mg/l doses of alum were applied at pH ranging from 4 to 10 and room temperature. An anionic polyelectrolyte was used for flocculation. The jar test experiments provided evidence that coagulation process could not provide sufficient COD removal efficiency in the Cuma and the University pilot plant wastewater even at an alum dose of 450 mg/l whereas the treatment with coagulation process using 150 mg/l alum in Nola and S. Giovanni plants was sufficient to meet COD (<160 mg/l) and TSS (80 mg/l) limits. The highest COD removal (80%) was obtained at the range of 6.0–8.0 pH values in the Nola plant (Marco et al, 2007).

Jalal et al (2021) examine the effectiveness of aluminium-based coagulant on textile wastewater quality. This study investigated that, aluminium based salts such as aluminium chloride and alum were proved best combination for treating wastewater. The result shows that that pH 6.5-7.5 found out to be an appropriate medium for maximum reduction of COD, color and turbidity. Treatment T5 reduced coloring content to 98% at pH 7, likewise 98% and 99% reduction in COD and turbidity were examined respectively. The investigation was made that pH 3 was least efficient pH for treating the wastewater for instance COD reduced to 98% with pH 7 whereas, 91% reduction was noticed at pH 3, same trend was observed for color and turbidity.

2.8.3 Ferric Chloride as Coagulant

Ferric chloride is the coagulant of choice for many industrial and sanitary wastewater treatment applications, due to its high efficiency, effectiveness in clarification, and utility as a sludge dewatering agent. A study conducted by Aghapour et al (2016) about nitrate removal from water using alum and ferric chloride. In their research, two coagulants, alum and ferric chloride, were compared for their efficiency in removing nitrate in a conventional water treatment system. The removal process was done in a batch system (jar test) to examine the effects of coagulant dosages and determine the conditions required to achieve optimum results. The results revealed that ferric chloride at an initial dose rate of 4 mg/L reduced nitrate concentration from 70 mg/L to less than the World Health Organization (WHO) guideline value (50 mg/L N-NO_3) However, the removal efficiency of alum was not salient to significant nitrate reduction. They conclude that ferric chloride was more effective than alum in removing nitrate.

Besides that, there was a study about treatment of biodiesel wastewater using ferric chloride and ferric sulphate. The effects of pH and coagulant dosage were examined at 150 rpm of rapid mixing and 20 rpm slow mixing and 30 min settling time. Optimum coagulant dose of ferric chloride and ferric sulphate were 300 mg/L and 450 mg/L, respectively. At optimum coagulant dose of ferric chloride, the removal of SS, colour, COD and oil and grease are 95%, 93%, 68% and 99% respectively as compared 86%, 83%, 59% and 90% were removed respectively at optimum dose of ferric sulphate (Daud et al, 2017).

Ferric chloride is efficient at pH range 4 and at optimal dose of 4g/L. Ferric chloride allows the reduction of 54% of chemical oxygen demand (COD) compare to other coagulants (Saraswati & Suresh, 2017). Barros et al (2022) conducted a test to determine the optimization of coagulation and flocculation process applied to the side stream of an urban wastewater treatment plant. This optimization resulted in the use of 25 mg/L of ferric chloride (FeCl3) combined with 25 mg/L of a flocculant composed of silicon (SiO2 3%), aluminum (Al2SO4 64.5%), and iron salts (Fe2O3 32.5). The numerical and statistical results of the process optimization reached 91.5%, 59.1%, and 95.2% removal efficiency for turbidity, COD, and TSS, respectively

2.8.4 Alum-Ferric Chloride

Jagaba et al, (2018) conducted a chemical precipitation by using combination of Alum and Ferric Chloride, each dose at pH 4.51, 250 rpm rapid mixing speed for 3 minutes, 30 rpm slow mixing speed for 30 minutes and 60 minutes settling time. Combination of different doses of Alum with 1 g/L dose of ferric chloride showed significant in pollutants load reduction in palm oil mill effluent (POME), 2 g/L alum + 1 g/L Fecl3 provides the highest removal percentages of colour, NH_3-N, oil & grease, Pb, Cd and Zn as 79.67%, 98.54%, 97.28%, 95.95%, 95.39% and 92.10% respectively while 77.65% COD removal was reached at 3 g/L alum + 1 g/L FeCl3 with not much variance compared to 75.52% obtained at 2 g/L alum + 1 g/L FeCl3. 99.59%, 86.05% and 92.19% removals were achieved for TSS, Cu and Mn respectively at combination dose of 1 g/L alum + 1 g/L FeCl3. Turbidity removal was best at 4 g/L alum + 1 g/L FeCl3 with an efficiency of 99.18%. 2 g/L alum + 1 g/L $FeCl_3$ combination dose with 21.25% as the percentage sludge volume is chosen as the optimum combination dose since most parameters performed better at the dose.

Xu et al., (2024) studied the advanced removal of phosphorus from urban sewage using chemical precipitation by Fe-Al composite coagulants. Total phosphorus (TP) removal rate of the $FeCl_3$-$AlCl_3$ composite coagulant is higher than $FeCl_3$ and $AlCl_3$ only at 10–30 mg/l. Compared with single coagulants of $FeCl_3$ and $AlCl_3$, the $FeCl_3$-$AlCl_3$ composite coagulant can significantly reduce the dosage and cost of P removal by chemical precipitation. For the 90% TP removal, the optimal dosages of single $FeCl_3$, AlCl3, and FeCl3-AlCl3 are 30.01, 38.52, and 21.85 mg/l, respectively. Fe-Al composite coagulants have a higher optimal TP removal rate than single coagulants when the pH is between 6 to 9. Polynuclear hydroxyl complexes are the primary hydrolysis product of Fe and Al salts coagulants at pH 6. The adsorption-bridging effect of the metal hydroxides hydrolyzed by Fe^{3+} and Al^{3+} plays an important role in P removal. Table 5 shows the summary of the various chemical coagulants and their effectiveness for the treatment of industrial wastewaters.

Table 5: A summary of the various chemical coagulants and their effectiveness for the treatment of industrial wastewaters

No.	Coagulant	Industry	Form of Coagulant	Optimum Dosage	Parameter Studied	Removal Efficiency	References
1	Lime	Textile dyes wastewater	Dry	600 mg/L	TSS	95%	El-Gohary and Tawfik, 2009
					Colour	100%	
					COD	50%	
2	Lime+ Magnesium Chloride	Textile dyes wastewater	Dry		Colour	97-100%	El-Gohary and Tawfik, 2009
					COD	40-50%	
3	Ferrous Sulfate with lime	Coal washery wastewater	Solution	400 ppm	Turbidity	56.67%	Babarao and Verma, 2015
4	Alum	Oil refinery wastewater	Powder	40 mg/L	Turbidity	92%	Dehghani and Alizadeh, 2016.
					TSS	82%	
5	Ferric chloride	Coal washery wastewater	Solution	400 ppm	Turbidity	98%	Babarao and Verma, 2015
6	Ferric chloride	Tannery wastewater	Powder	150 mg/L	BOD	81%	Ahmed et al., 2016
					Turbidity	72%	
					TSS	95%	
					TDS	71%	
					Cr	93%	
7	Ferric Chloride and Aluminium Sulfate	Hospital wastewater	Dry		COD	85%	Suarez at al., 2009
					TSS	92%	
					Diclofenac (DCF)	46%	
					Naproxen (NPX)	42%	

Table 6: A summary of the various chemical coagulants and their effectiveness for the treatment of industrial wastewaters (continued)

No.	Coagulant	Industry	Form of Coagulant	Optimum Dosage	Parameter Studied	Removal Efficiency	References
8.	Lime	Textile dyes wastewater	Dry	600 mg/L	Phosphorus	80%	Mortula et al, 2020)
	Dried Lives				BOD	100%	
	Polymer				Turbidity	50%	
9.	Calcium fluoride + hydroxyapatite	Semiconductor Wastewater	Dry		Phosphorus	99.99%	Ho et al, 2023
10.	Ferrous Sulfate with lime	Landfill Leachate	Solution	400 ppm	Ammonia	56.67%	Chen et al, 2013
11.	quicklime (CaO)	Electronic Wastewater	Solution	400 ppm	Turbidity	98%	Babarao and Verma, 2015
	ferrous sulfate (FeSO4)						

2.9 Effect of Electronic Effluents on Receiving Water Environments

Phosphorus, nitrogen, and carbon are essential nutrients for aquatic health, but too much of them can be harmful. As a result, wastewater treatment plants must adhere to nutrient effluent limits for phosphorus, nitrogen, carbon, and other micronutrients found in wastewater (Curtin, 2011). Water quality in a lake or reservoir in Malaysia can be influenced by external inputs from the watershed as well as the in-lake ecosystem, nutrient cycling, and internal loading. External inputs can include organic and inorganic pollutants, as well as nutrients, which cause water quality degradation from both point and non-point sources. Eutrophication will result from an excessive amount of nutrients like phosphorous and nitrogen being introduced to lakes and reservoirs. Due to the enrichment of plant nutrients, particularly phosphorus and nitrogen as dissolved solutes and as compounds bound to organic and inorganic matters from natural and anthropogenic sources, a water body becomes uncontrollably rich and abundant in aquatic plants like algae and aquatic macrophytes (water weeds) (Salameh et al, 2011). The equilibrium of the aquatic species and the water's quality will be adversely affected by eutrophication.

CHAPTER 3

METHODOLOGY

3.1 Background

This chapter described the setups of the chemical precipitation systems as well as the overall experimental process. The materials and methods used were also presented. The experimental research was performed as follows:

i. The electronic wastewater collected from the industry will be characterize according to APHA method.
ii. The electronic wastewater collected from the industry will be chemically treated with chemical precipitation using different coagulants which are alum, ferric chloride, alum-lime coagulant, and alum-ferric coagulant. This is to study the effectiveness of different jar test regime using coagulants in removing organic and nitrogen compound from the industrial discharge of electronic industry and to determine the optimum dosage and pH for each coagulant.

3.2 Flow of Work

The study will start as soon the sample wastewater will be collected from electronic factory. Wastewater sample were being stored in cold room for preservation located in Block 14-02-02. The wastewater collected will be tested for characterization before being used in chemical precipitation system using jar test. For the first objective, the samples will be treated using jar tests to study the effectiveness of different jar test regime using coagulants in removing organic and nitrogen compound from the industrial discharge of electronic industry. The optimum dosage and pH. In the optimum pH, the dosage of the coagulant will be kept constant with varying pH from pH 2-12. The optimum pH obtained from this test will be used for the second jar test to determine the optimum dosage. In this jar test, the pH will keep constant, and the dosage of the coagulant will be varied. Several tests will be conducted to determine the best optimum dosage.

For the second objective, the jar test will determine the optimum pH and optimum dosage of alum, ferric chloride, , alum-ferric coagulant, and alum-lime coagulant in removal of organic and nitrogen through APHA method. The setup of the chemical precipitation system that will be constructed using jar tests as depicted in Figure 5.

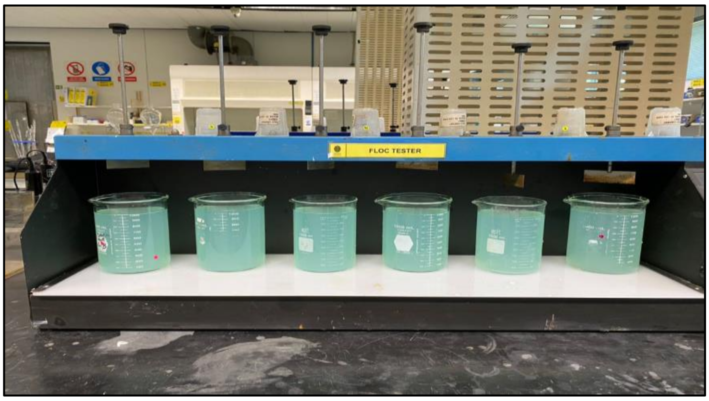


Figure 5: Jar Test for Chemical Precipitation System

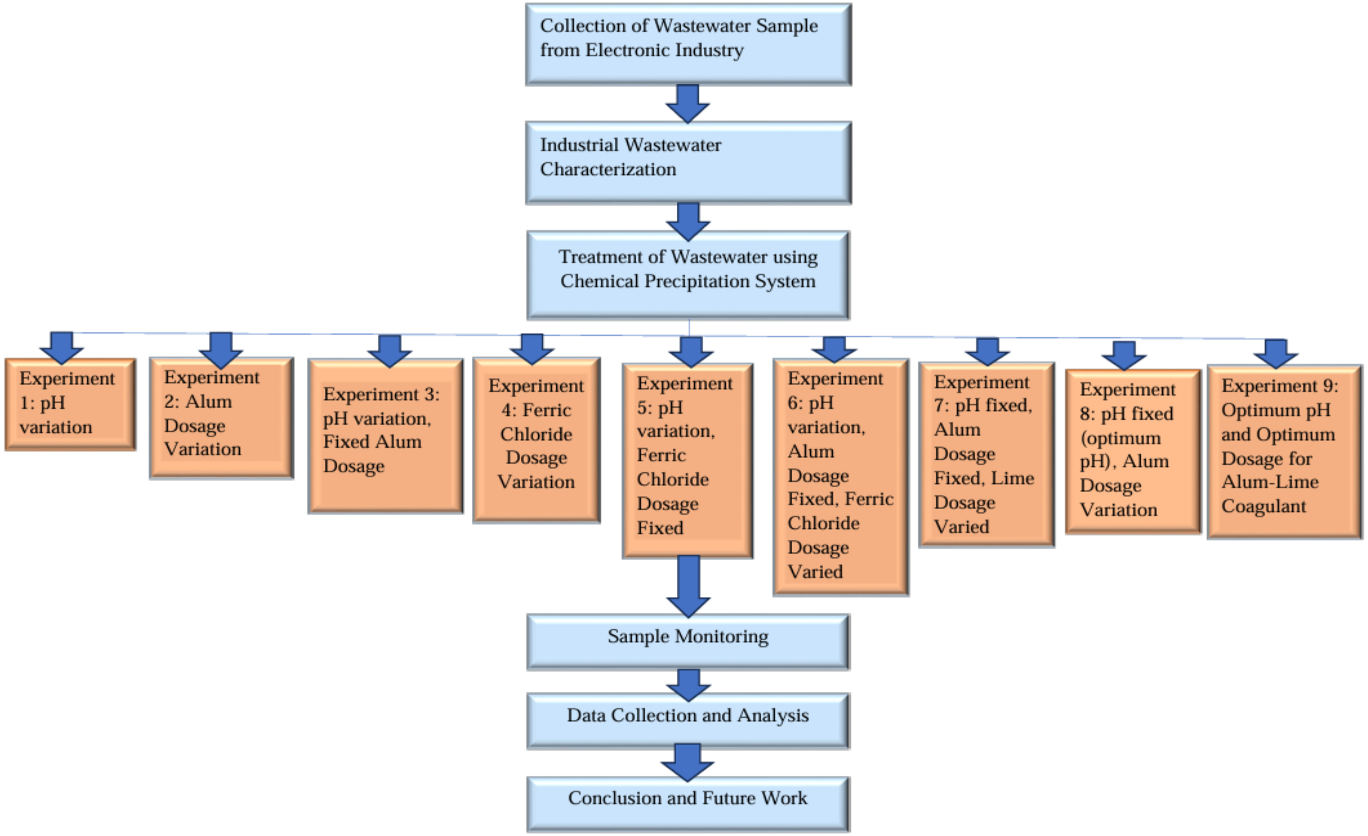


Figure 6: Flow of Work for the Project

3.3 Experimental Methodology

In the chemical precipitation process, two parameters will be accounted for the performance of the system. Table 7 shows the experimental methodology:

- Dosage of Coagulant (15 min, 30 mins, 45 mins, 60 mins)
- pH

Table 7: Experiment Methodology

Experiments	Jar Test	Variable	Jar						Frequency
			1	2	3	4	5	6	
1	pH Variation	pH	2	4	6	8	10	12	3
2	Alum Dosage Variation	Alum Dosage	15 mg/L	50 mg/L	100 mg/L	200 mg/L	300 mg/L	500 mg/L	3
3	pH Variation, Fixed Alum Dosage	pH	2	4	6	8	10	12	3
		Alum Dosage	100 mg/L	100 mg/L	100 mg/L	100 mg/L	100 mg/L	100 mg/L	
4	Ferric Chloride Dosage Variation	Ferric Chloride Dosage	45 mg/L	90 mg/L	135 mg/L	180 mg/L	225 mg/L	270 mg/L	3
5	pH Variation, Ferric Chloride Dosage Fixed	pH	2	4	6	8	10	12	3
		Ferric Chloride Dosage	180 mg/L	180 mg/L	180 mg/L	180 mg/L	180 mg/L	180 mg/L	
6	pH Variation, Alum-Ferric Chloride Dosage Variation	pH	2	4	6	8	10	12	3
		Alum Dosage	50 mg/L	100 mg/L	150 mg/L	200 mg/L	250 mg/L	300 mg/L	
		Ferric Chloride Dosage	45 mg/L	90 mg/L	135 mg/L	180 mg/L	225 mg/L	270 mg/L	

Experiments	Jar Test	Variable	Jar						Frequency
			1	2	3	4	5	6	
7	Fixed Alum Dosages, Varied Lime Dosages	pH	10						
		Alum	100 mg/L	100 mg/L	100 mg/L	100 mg/L	100 mg/L	100 mg/L	3
		Lime	15 mg/L	50 mg/L	100 mg/L	200 mg/L	300 mg/L	500 mg/L	
8	Optimum pH alum, Optimum Dosage alum	pH	10						3
		Dosages	500 mg/L						
	Optimum pH Alum-lime, Optimum Dosage Alum-lime	pH	10						3
		Alum Dosages	500 mg/L						
		Lime Dosages	200 mg/L						

The experiment will be divided into 8:

3.3.1 Experiment 1:

In the Experiment 1, one-liter wastewater samples will be distributed across six jars. In this particular variation, the dosage of the coagulant (alum) will be deliberately excluded. Instead, the focus will be on exploring different pH levels, specifically at values of 2, 4, 6, 8, 10, and 12. Each jar will be subjected to these distinct pH conditions. Subsequently, the samples will undergo a rapid mixing phase (150 rpm) lasting approximately 1 minute. Following this, a flocculation process of 15 minutes will be applied to the samples, and a subsequent sedimentation process will be carried out for 20 minutes. Throughout the experiment, the final pH of the samples will be closely monitored. The pH was adjusted by using sulfuric acid and sodium hydroxide to restore and attain the desired pH levels. This experiment aims to investigate the influence of varying pH conditions, without the presence of coagulant, on the wastewater treatment process. The wastewater sample will then undergo analysis for organic and nutrient presence such as COD, TSS, Ammonia Nitrogen, Nitrate Nitrogen, Turbidity and Total Phosphorus using APHA method.

3.3.2 Experiment 2:

In Experiment 2, a similar setup to Experiment 1 will be maintained, with one-liter wastewater samples allocated to each of the six jars. However, this time the focus will be on investigating the joint effects of varying pH and alum dosage. The alum dosage will be adjusted at 15 mg/L, 50 mg/L, 100 mg/L, 200 mg/L, 300 mg/L, and 500 mg/L for all jars, without the variation of pH. Upon the addition of the coagulant (alum), the samples will undergo rapid mixing for approximately 1 minute. Subsequently, the samples will be subjected to a flocculation process lasting 15 minutes, followed by a sedimentation process lasting 20 minutes. This experiment aims to elucidate the combined impact of varying alum dosages on the wastewater treatment process. The wastewater sample will then undergo analysis for organic and nutrient presence such as COD, TSS, Ammonia Nitrogen, Nitrate Nitrogen, Turbidity, pH and Total Phosphorus using APHA method.

3.3.3 Experiment 3:

In Experiment 3, a fixed alum dosage was employed while varying the pH levels to assess their impact on the coagulation process. The pH levels tested were 2, 4, 6, 8, 10, and 12, with each sample treated with a constant alum dosage of 100 mg/L. Initially, a one-liter sample of wastewater was placed in each of the six jars. Subsequently, the desired pH levels were achieved by adjusting the acidity or alkalinity of the samples using appropriate chemicals such as sulfuric acid or sodium hydroxide. Once the pH of each sample reached the target value, alum was added to all jars at a constant dosage of 100 mg/L. Following the addition of alum, the samples underwent a rapid mixing phase for approximately 1 minute to ensure proper dispersion of the coagulant throughout the container. This was followed by a period of flocculation lasting 15 minutes, during which the formation of flocs occurred. Finally, a 20-minute sedimentation phase was implemented to allow the settled flocs to separate from the treated wastewater. This methodology aimed to assess the effectiveness of alum as a coagulant under different pH conditions in wastewater treatment. Subsequently, the treated wastewater samples were subjected to analysis to determine the presence of organic and nutrient compounds, including Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), Ammonia Nitrogen, Nitrate Nitrogen, Turbidity, and Total Phosphorus, utilizing methods prescribed by the APHA method.

3.3.4 Experiment 4:

In Experiment 4, the focus was solely on varying the dosage of ferric chloride as the coagulant while keeping other parameters constant. The ferric chloride dosages tested were 45 mg/L, 90 mg/L, 135 mg/L, 180 mg/L, 225 mg/L, and 270 mg/L. The experimental setup involved filling six jars, each containing one liter of wastewater sample. Subsequently, ferric chloride was added to each jar at the designated dosage, as specified above. After the addition of ferric chloride, the samples underwent a rapid mixing phase for approximately 1 minute to ensure proper dispersion of the coagulant throughout the container. This was followed by a 15-minute flocculation period to allow the formation of flocs. Following the flocculation phase, a 20-minute sedimentation process was initiated to facilitate the settling of suspended particles. Throughout the experiment, the behavior of the samples at different ferric chloride dosages was closely monitored. Subsequently, the treated wastewater samples would undergo analysis to determine the presence of organic and nutrient compounds, including Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), Ammonia Nitrogen, Nitrate Nitrogen, Turbidity, and Total Phosphorus, utilizing methods prescribed by the American Public Health Association (APHA) or other relevant standards.

3.3.5 Experiment 5:

In Experiment 5, the objective was to investigate the influence of varying pH levels on the effectiveness of ferric chloride as a coagulant. The experiment involved maintaining a constant ferric chloride dosage of 180 mg/L while adjusting the pH levels across six different conditions: pH 2, 4, 6, 8, 10, and 12. The experimental procedure began by preparing six separate jars, each containing one liter of wastewater sample. Subsequently, the pH of each sample was individually adjusted to the desired level using appropriate chemicals, such as sulfuric acid or sodium hydroxide. Once the pH of each sample reached the target value, ferric chloride was added to all jars at a fixed dosage of 180 mg/L. After the addition of ferric chloride, the samples underwent a rapid mixing phase for approximately 1 minute to ensure thorough dispersion of the coagulant throughout the container. Following the rapid mixing phase, a 15-minute period of flocculation was implemented to facilitate the formation of flocs within the wastewater samples. This was followed by a 20-minute sedimentation phase to allow the settled flocs to separate from the treated wastewater. The objective was to assess the effectiveness of ferric chloride as a coagulant under varying pH conditions and to determine the optimal pH range for coagulation in wastewater treatment. Subsequently, the treated wastewater samples would undergo analysis to determine the presence of organic and nutrient compounds, including Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), Ammonia Nitrogen, Nitrate Nitrogen, Turbidity, and Total Phosphorus, utilizing methods prescribed by relevant standards such as those provided by the American Public Health Association (APHA).

3.3.6 Experiment 6:

In Experiment 6, the aim was to investigate the combined effect of varying pH levels and dosage of two coagulants, alum and ferric chloride, on the coagulation process. The experiment involved testing different combinations of pH levels, alum dosages, and ferric chloride dosages. The experimental setup consisted of preparing six jars, each containing one liter of wastewater sample. The pH of each sample was adjusted to one of the designated levels: pH 2, 4, 6, 8, 10, and 12. Additionally, each sample was treated with a specific combination of alum and ferric chloride dosages. The alum dosage varied across the samples from 50 mg/L to 300 mg/L, while the ferric chloride dosage ranged from 45 mg/L to 270 mg/L. After adjusting the jar, the samples underwent a rapid mixing phase for approximately 1 minute to ensure thorough dispersion of the coagulants. Subsequently, a 15-minute flocculation period was implemented to allow for the formation of flocs, followed by a 20-minute sedimentation phase to facilitate the settling of suspended particles. The objective was to assess the combined effects of pH variation and alum-ferric chloride dosage variation on the coagulation process and to determine the optimal conditions for achieving effective removal of organic and nutrient from the wastewater samples. Subsequently, the treated wastewater samples would undergo analysis to determine the presence of organic and nutrient compounds, including Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), Ammonia Nitrogen, Nitrate Nitrogen, Turbidity, and Total Phosphorus, utilizing methods prescribed by relevant standards such as those provided by the American Public Health Association (APHA)..

3.3.7 Experiment 7:

In Experiment 7, the objective was to examine the impact of varying lime dosages on the coagulation process while maintaining fixed alum dosages. This experiment aimed to determine the optimal lime dosage for pH adjustment and its effect on coagulation efficiency. The experimental setup involved preparing six jars, each containing one liter of wastewater sample with a pH level set at 10. The alum dosage was kept constant at 100 mg/L for all samples. Different lime dosages were added to each sample, ranging from 15 mg/L to 500 mg/L. These lime dosages were selected to cover a broad spectrum of pH adjustment levels. Following the addition of lime, the samples underwent a rapid mixing phase for approximately 1 minute to ensure proper dispersion of the lime throughout the container. Subsequently, a 15-minute flocculation period was implemented to facilitate the formation of flocs, followed by a 20-minute sedimentation phase to allow the settled flocs to separate from the treated wastewater. The objective was to assess the effectiveness of lime as coagulant aid and its influence on the coagulation process. Subsequently, the treated wastewater samples would undergo analysis to determine the presence of organic and nutrient compounds, including Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), Ammonia Nitrogen, Nitrate Nitrogen, Turbidity, and Total Phosphorus, utilizing methods prescribed by relevant standards such as those provided by the American Public Health Association (APHA).

3.3.8 Experiment 8:

Experiment 8 was conducted to determine the optimum pH and dosage parameters for Aluminum Sulfate, Ferric Chloride, Alum-Ferric Coagulant, and Alum-Lime Coagulant in wastewater treatment. Each coagulant or coagulant combination was tested at a fixed pH of 10. For Aluminum Sulfate, the optimal dosage was identified as 500 mg/L. In the case of Alum-Lime Coagulant, the optimal dosage was found to be Alum at 500 mg/L with 200 mg/L of Lime. These dosages were carefully chosen to cover a range of concentrations and to pinpoint the most effective dosage for each coagulant or combination. Following treatment, comprehensive analysis was conducted on the treated wastewater samples using methods APHA method to validate the efficiency of the optimized coagulation parameters in achieving desired treatment outcomes.

3.4 Sampling Monitoring and Testing Method

The wastewater collected from electronic factory will be treated using chemical precipitation systems as proposed above. Effluent from the system will be analyses for parameters such Ammonia-Nitrogen, Nitrate-Nitrogen, Total Phosphorus, COD, TSS, and Turbidity. All wastewater analyses shall be conducted according to the International Standard Methods (APHA). Throughout the study, wastewater samples will be collected in weekday and it will be measured in triplicates to ensure results consistency. The parameters to be analyse for each train will be according to Table 8 below.

Table 8: Parameter, APHA Method and frequency tested.

Parameters	APHA method	Frequency
Ammonia Nitrogen	4500-NH_3	triplicates
Nitrate Nitrogen	4500-NO_3	triplicates
Total Phosphoros	4500-P	triplicates
COD	5220	triplicates
Turbidity	2130	triplicates
TSS	2450-D	triplicates
pH	4500-H^+	triplicates

3.5 Wastewater Parameters Test Procedures

In this study, the parameters that will be tested are Ammonia-Nitrogen, Nitrate-Nitrogen, Total Phosphorus, COD, TSS, and pH. Table 5 showed the materials and methods use during the testing.

3.5.1 Procedure for Measurement of Ammonia (NH_3-N)

The procedure for measuring Ammonia concentration includes diluting the wastewater sample with a dilution factor of 1:10 using a volumetric flask. 25 mL of diluted sample was inserted in a measuring cylinder and mixed with three drops of mineral stabilizer, followed by three drops of polyvinyl alcohol. Then, the sample was mixed with 1 mL of Nessler reagent for one minute. A blank sample was prepared with distilled water mixed with three drops of mineral stabilizer, three drops of polyvinyl alcohol, and 1 mL of Nessler reagent. Three cuvettes were filled with the mixed sample while the blank cuvette was filled with distilled water. The program used to determine Nitrogen level is program 380 N, Ammonia, Ness in the spectrophotometer. The blank sample was inserted into the spectrophotometer to be zeroed. Then, the cuvette sample mix is inserted into a spectrophotometer to read, and values were recorded.

3.5.2 Procedure for Measurement of Nitrate (NO_3-N)

The procedure of measuring Nitrate concentration started with preparing four cuvettes filled with 10 ml of wastewater sample, respectively. One of the cuvettes acts as a blank while the other three cuvettes were added with NitraVer5 Nitrate Reagent Powder Pillow. The cuvettes were shaken for one minute and were left still for five minutes for the reaction to take place. A visual color change will be seen to dictate the presence of Nitrate in the sample. The program used to determine Nitrate level is program 355 Nitrate HR PP in a spectrophotometer. The blank cuvette sample was added to the spectrophotometer to be zero. Then, the cuvette samples with NitraVer5 powder pillow were inserted into a spectrophotometer to read and values were recorded.

3.5.3 Procedure for Measurement of Phosphorus (PO_4^{3-})

The procedure for measuring the concentration of Phosphorus started by preheating DRB200 Reactor to 150°C. Then, four test vials were added with 5 mL of wastewater sample that was diluted to 1:5, and a potassium persulfate pillow each. The vials were mixed using Vibrator Vortex and left in DRB200 Reactor for 30 minutes. After 30 minutes, the vials were left to cool to room temperature. Next, 2 mL of 1.54N sodium hydroxide were added using pipette into the vials each and mixed. This acts as the blank sample and inserts into a spectrophotometer to be zero. PhosVer3 powder was then added into each vial and mixed for two minutes. The visual colour change will be observed to dictate the presence of Phosphorus in the vial. Then, the vials were inserted into the spectrophotometer to be read and values were recorded.

3.5.4 Procedure for Measurement of COD

The procedure for measuring the concentration of COD started by preheating DRB200 Reactor to 105°C. Then, 2 mL of wastewater sample was measured and pour into a test tube containing potassium dichromate. After that, the test tubes were shakes properly. When heat is produced, it indicates an exothermic process. Next, all the test tubes together with a blank as an indicator were then put into the COD reactor and left for 2 hours. After two hours the tubes were removed from the reactor and allowed them to cool to room temperature.

Then, the tubes were inserted into the spectrophotometer to be read and values were recorded. The spectrophotometer was set to the appropriate wavelength. Three readings were taken and the average of those readings were calculated.

3.5.5 Procedure for Measurement of TSS

The procedure for measuring the concentration of TSS was started by labelling the aluminum pan so that it can be identified easily. Next, the weight of the filter paper and the pan were measured and recorded. After that, the TSS filter pump was cleaned using distilled water. Next, a filter paper was placed on top of the filter holder. 50 mL influent and 100 mL effluent of wastewater were measured using measuring cylinder and poured them into the filter. This step was repeated for 2 other samples. The measuring cylinder was rinsed using distilled water. Next, the pump was switched on to let the wastewater sample pump out. The distilled water was added to make sure no suspended solids stick to the side of the filter. Once all the water is pumped out, the watch glass is removed and placed the filter paper containing the solids on the pan. Next, the pan and the filter paper were placed in the drying oven at 105˚C for one hour. After the one hour, the pan and the filter were removed from the drying oven and they were placed in a desiccator for 10 minutes to cool down to room temperature. Lastly, the pan together with the filter paper and solids were weighted using analytical balance. The results were divided into initial weight of foil with filter paper (mg), final weight of foil with filter paper after 105 °C (mg), final weight foil with filter paper after 150 °C (mg), TSS value, and average TSS.

3.5.6 Procedure for Measurement of pH

The electrodes were removed from the storage solution, rinse, and dried with soft tissue. The electrodes were dipped into the buffer solution of known pH which is pH 4 to calibrate the pH meter. Press calibrates in the pH meter and press read while waiting the sample to stabilize. Ensure that the reading in the stabilize buffer solution is 4.0. After that, the electrode was taken out from the buffer solution and cleaned with distilled water. After cleaning, the electrodes were wiped using soft tissue and the electrode was dipped into the buffer solution of known pH 7. The reading was recorded. Next, the electrode was taken out from the buffer solution and cleaned with distilled water. The electrode was wiped using soft tissue. After that, the electrode was dipped into the buffer solution of known pH 10. Then, the electrode was taken out from the buffer solution and cleaned with distilled water. The electrode was wiped using soft tissue. Next, the pH meter was calibrated for all the pH 4, pH 7, and pH 10. Next, the electrode was cleaned using distilled water and the electrode was dipped into the wastewater sample and the reading value from the pH meter was recorded. Three readings were taken and the average of those pH readings were calculated.

3.5.7 Procedure for Measurement of Turbidity

Turbidimeter was turned on and left to warm up for a few minutes. The vial containing the prepared wastewater samples was cleaned using kimwipes tissue. The air bubbles were waited until it was disappeared and poured the sample into the turbidimeter tube. When possible, the shaken sample was poured into the turbidimeter tube and ensured complete bubble release. The vial was carefully placed inside the cell holder of the turbidimeter, ensuring that the point on the vial faced the point on the turbidimeter. The lid was closed, and the reading was taken by pressing the read button on the turbidimeter. The reading was taken after it had stabilized. This process was repeated for other samples. Three readings were taken, and the average of those Turbidity readings was calculated.

Table 9: Materials and Methods

Parameter	Materials & Reagents	Method
Ammonia Nitrogen	Nessler reagent, polyvinyl alcohol, mineral stabilizer, 100mL flask, 1 pipette, sample cells cuvette, DR3900 spectrometer and distilled water.	APHA 4500-NH3
Nitrate Nitrogen	Sample cells, Nitraver5 reagent powder pillow, beakers DR3900 spectrometer and 10mL measuring cylinder.	APHA 4500-NO3
Total Phosphorus	DRB200 digestion reactor, glass pipette, PO_4 digestion vial, wastewater samples, potassium persulfate powder, sodium hydroxide, DR3900 spectrophotometer and distilled water.	APHA 4500-P
COD	Refluxing unit, DRB200 digestion reactor, Pipette, Spectrophotometer, Chromic acid, Chromic acid, Sulfuric acid solution, Mercuric sulphate, Ferroin indicator, and Potassium dichromate solution	APHA 5220
TSS	Dry oven, Analytical balance, Desiccator, Dish tong, Measuring cylinder, Filter paper, Glass fibre filter, Furnace, TSS filter pump, Aluminium pan, Wastewater sample, Distilled water	APHA 2540-D
pH	pH meter with electrode, beaker, standard buffer solution, water sample, distilled water.	APHA 4500-H^+
Turbidity	Turbidimeter and Vial	APHA 2130

3.6 3.5 Gantt Chart

3.6.1 Gantt Chart Research Project 1 (RP1)

Table 10: Gantt Chart RP1

No	Details/Work	Week											
		1	2	3	4	5	6	7	8	9	10	11	12
1	Selection of Project Title	🟩											
2	Literature Review • Collection of research paper related to the title.		🟩	🟩	🟩	🟩	🟩						
4	Submission of Extended Project Proposal							🟩					
5	Collect wastewater sample from electronic manufacturer company									🟩			
6	RPD report submission											🟩	
7	Proposal Defence Oral Presentation												🟩

3.6.2 Gantt Chart Research Project 2 (RP2)

Table 11: Gantt Chart RP2

No	Details/Work	Week													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project Title	🟩													
2	Literature Review • Collection of research paper related to the title.		🟩	🟩	🟩	🟩	🟩								
3	Collect wastewater sample from electronic manufacturer company	🟩													
4	Conduct Jar Test Experiment		🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩					
5	Submission of Progress Report and Form 03							🟩							
6	Submission of Progress Report											🟩			
7	Oral Presentation												🟩		

CHAPTER 4
RESULTS AND DISCUSSIONS

The results of the study on the impact of different coagulants on organic and nutrient removal using jar test are presented in this section.

4.1 Characterization of Electronic Wastewater

The section analysed the characteristics of electronic wastewater. The pH value of raw influent wastewater collected from the equalization tank is 5.52 as table 12 below:

Table 12: Characterization of Electronic Wastewater

Parameters	Unit	Influent Wastewater	DOE Standard B Discharge Limit
Chemical Oxygen Demand (COD)	mg/L	1574	200
Ammoniacal Nitrogen	mg/L	84	20
Nitrate Nitrogen	mg/L	6.4	50
Total Phosphorus	mg/L	106.4	10
Total Suspended Solid (TSS)	mg/L	185	100
Turbidity	mg/L	162	
Zinc	mg/L	23.2	2
Boron	mg/L	25.6	4

4.2 Comparison of Organic and Nutrient Removal by coagulant variation.

This section describes the results of organic and nutrient removal by chemical precipitation using Aluminum Sulfate, Ferric Chloride, Alum-Ferric chloride coagulant, and Alum-Lime coagulant. The efficiency of the removal was determined by obtaining the optimum pH and dosage of the precipitant.

4.2.1 Results of Experiment 1: Varying the pH of Electronic Wastewater

4.2.1.1 Effluent COD Results throughout the Study

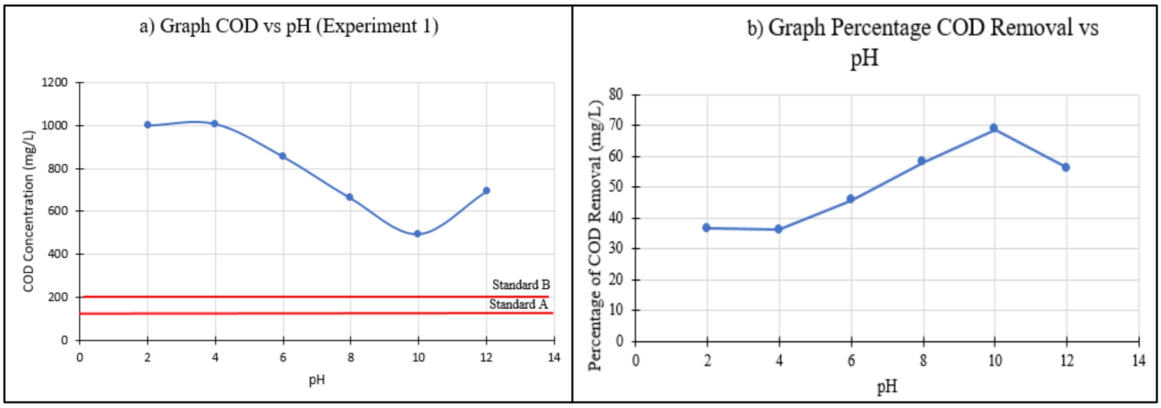


Figure 7: Result of (a) COD concentration vs pH and (b) Percentage COD removal vs pH

The pH value was significantly affected the efficiency of organics removal. pH range between 2, 4, 6, 8, 10, and 12 were chosen to conduct the jar test experiment for choosing the optimum pH for the coagulant precipitation. Based on the line graph for the COD in Figure 7, it can be observed a decrease at pH 6, pH 8, and pH 10. There was a slightly increases at pH 4 and 12. The highest COD removal was 68.7% which at pH 10 while the lowest COD removal was 36.1 % at pH 4. Based on the results of the final COD concentration, there were only slightly changes. Table 13 shows the average COD removals. However, all the effluent COD still does not meet the standard B discharge limit of 200 mg/L.

Table 13: Averaged COD Removals (%)

pH	Average COD removal (%)
2	36.6
4	36.1
6	45.7
8	58.1
10	68.7
12	56.2

4.2.1.2 Effluent Turbidity Results throughout the Study

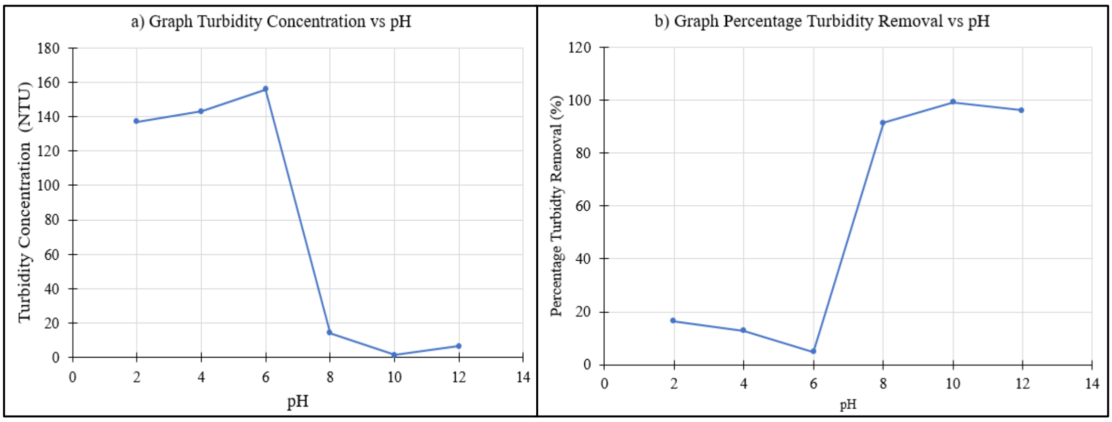


Figure 8: Result of Turbidity Value vs pH (a) and Percentage Turbidity Removal vs pH (b)

From Figure 8a, it can be observed that there is an increase in turbidity values at pH 2, 4, and 6, whereas there is a decrease at pH 8 and pH 10. The highest turbidity removal was 99.1% (Figure 8b), which occurred at pH 10, while the lowest turbidity removal was 4.9% at pH 6. Table 14 presents the average percentage of turbidity removal.

Table 14: Averaged Turbidity Removals

pH	Average turbidity removal (%)
2	16.5
4	12.8
6	4.9
8	91.3
10	99.1
12	96.1

4.2.1.3 Effluent Total Suspended Solid (TSS) Results throughout the Study

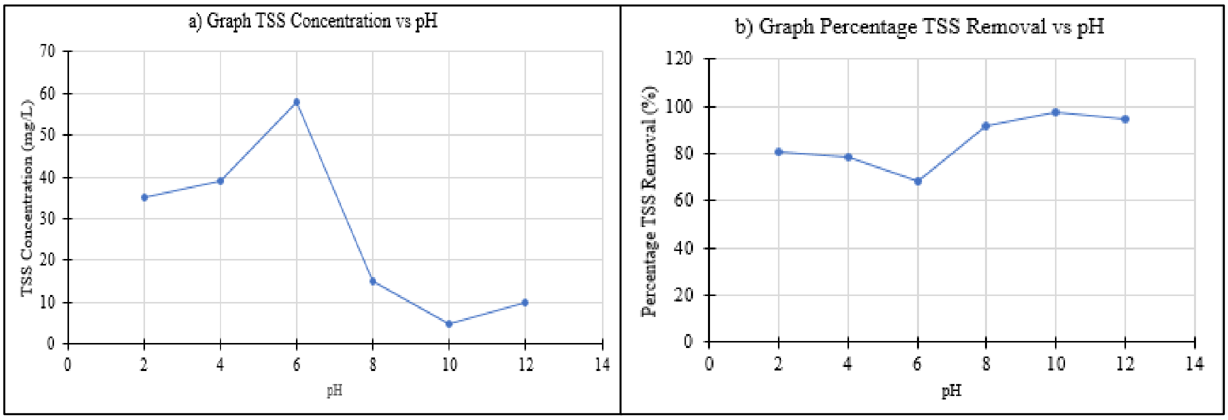


Figure 9: Effluent (a) Total Suspended Solid (TSS) vs pH and (b) Percentage TSS Removal vs pH

From Figure 9a, a decrease in TSS concentration is observed from pH 8 to pH 10, while there is a slight increase at pH 2 to pH 6. The highest TSS removal, 97.3%, occurs at pH 10, whereas the lowest removal, 68.6%, is observed at pH 6. These results indicate that pH 10 are highly efficient in removing TSS, meeting the standard A discharge limit for industrial wastewater which is 120 mg/L. Table 15 presents average TSS removals throughout the study for each pH.

Table 15: Average TSS removal

pH	Average TSS removal (%)
2	81.1
4	78.9
6	68.6
8	91.9
10	97.3
12	94.6

4.2.1.4 Effluent Nitrate-Nitrogen Results throughout the Study

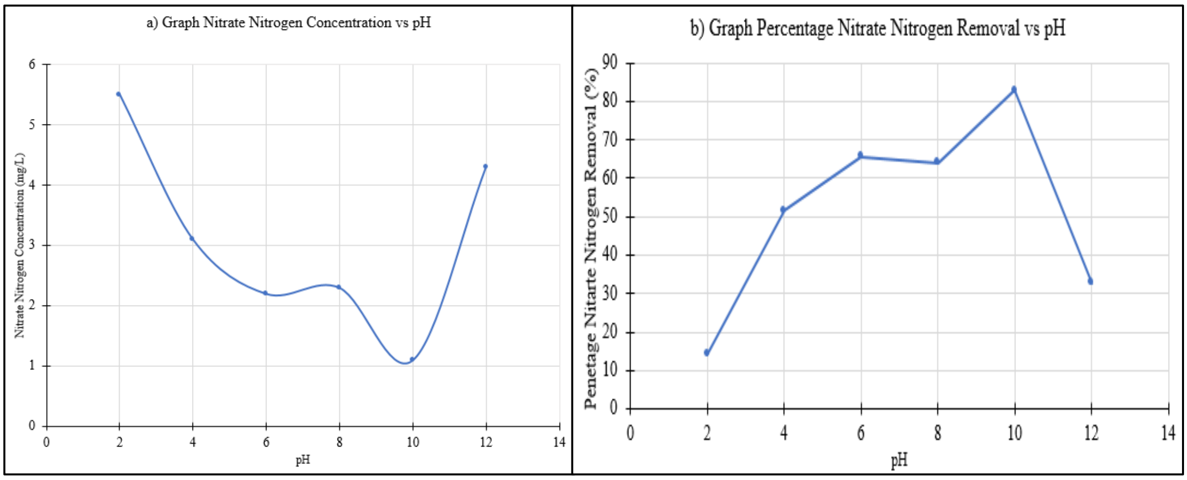


Figure 10: Effluent (a) Nitrate Nitrogen vs pH and (b) Percentage Nitrate Nitrogen Removal vs pH

From Figure 10, it can be observed a lowest decreasing at pH 10, but there was a slightly increases at pH 12 with average nitrate concentration of 4.3 mg/L but within the standard A limit of 20mg/L. The highest nitrate removal was 82.8% which at pH 10. Each value was meeting standard A of 20mg/L. Table 16 shows the average nitrate removals throughout the study period for each pH.

Table 16: Average Nitrate Removals

pH	Average nitrate removal (%)
2	14.1
4	51.6
6	65.6
8	64.1
10	82.8
12	32.8

4.2.1.5 4.2.1.5 Effluent Ammonia-Nitrogen Results throughout the Study

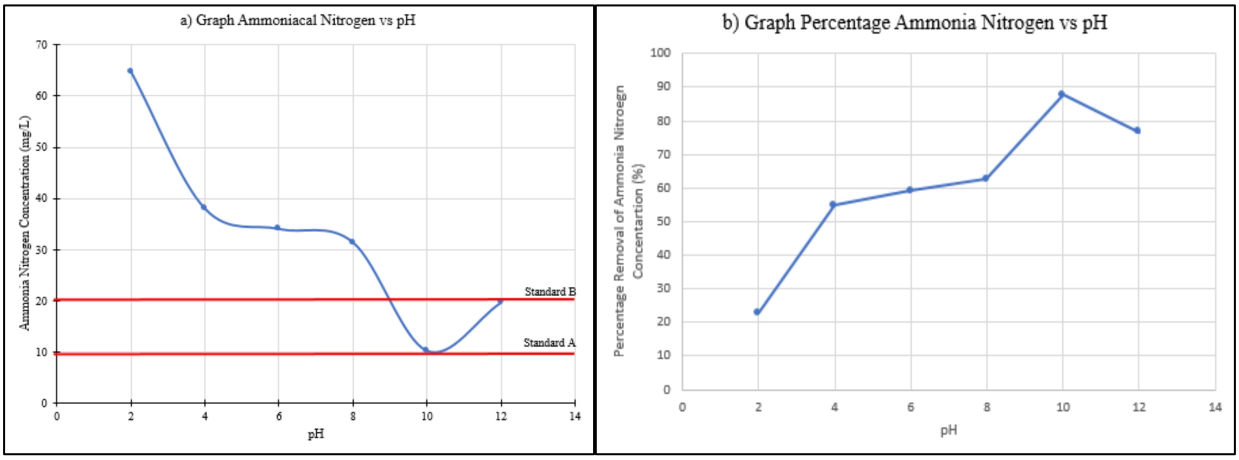


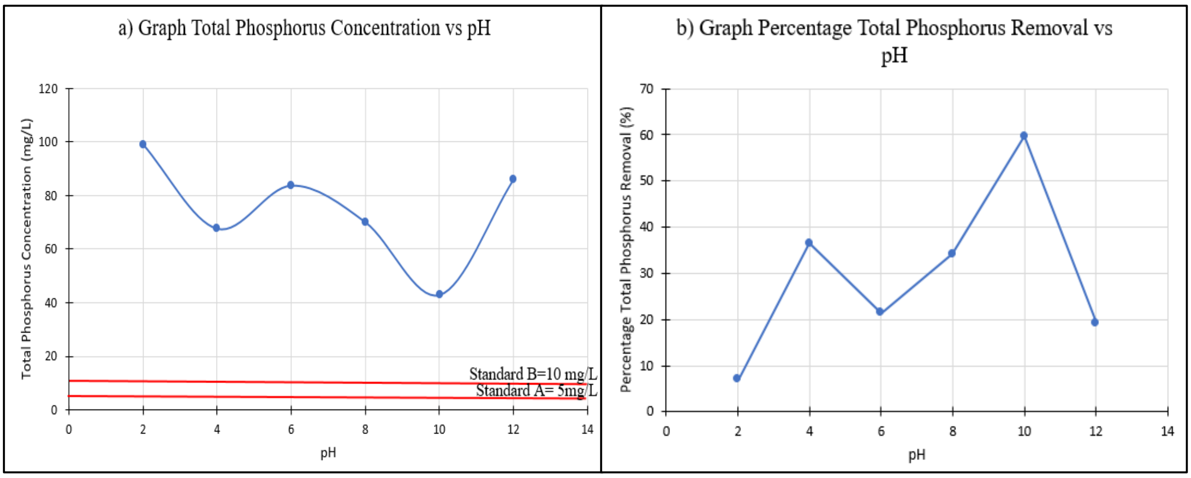
Figure 11: Effluent (a) Ammonia Nitrogen vs pH and (b) Percentage Ammonia Nitrogen vs pH

From Figure 11, a decrease in ammonia concentration is observed from pH 2 to pH 10. The highest ammonia removal, 87.9%, occurs at pH 10, whereas the lowest removal, 22.9%, is observed at pH 2. These results indicate that pH 10 are highly efficient in removing ammonia, meeting the standard A discharge limit for electronic wastewater. Table 17 shows the average effluent ammonia nitrogen concentration throughout the study period for each pH and the average ammonia nitrogen removals.

Table 17: Average Ammonia Removal

pH	Average ammonia removal (%)
2	22.9
4	54.8
6	59.2
8	62.6
10	87.8
12	76.7

4.2.1.6 Effluent Total Phosphorus Results throughout the Study


a) Graph Total Phosphorus Concentration vs pH

b) Graph Percentage Total Phosphorus Removal vs pH

Figure 12: Effluent (a) Total Phosphorus vs pH and (b) Percentage Total Phosphorus Removal

From Figure 12a, a decrease in total phosphorus concentration is observed from pH 6 to pH 10, while there is a slight increase at pH 12. The highest total phosphorus removal, 59.6%, occurs at pH 10, whereas the lowest removal, 7%, is observed at pH 2. For pH values ranging from 2 to 12, the final total phosphorus concentrations are 99.0 mg/L, 67.6 mg/L, 83.6 mg/L, 70.0 mg/L, 43.0 mg/L, and 86.0 mg/L, respectively. These results indicate that pH 10 is highly efficient in removing total phosphorus but does not meet the standard B discharge limit of 10 mg/L for industrial wastewater. Table 18 shows the average total phosphorus removals throughout the study period for each pH and.

Table 18: Average Total Phosphorus removal

pH	Average total phosphorus removal (%)
2	7
4	36.5
6	21.4
8	34.2
10	59.6
12	19.2

4.2.2 Results of Experiment 2: Varying the Alum Dosage of Electronic Wastewater

4.2.2.1 Effluent COD Results throughout the Study

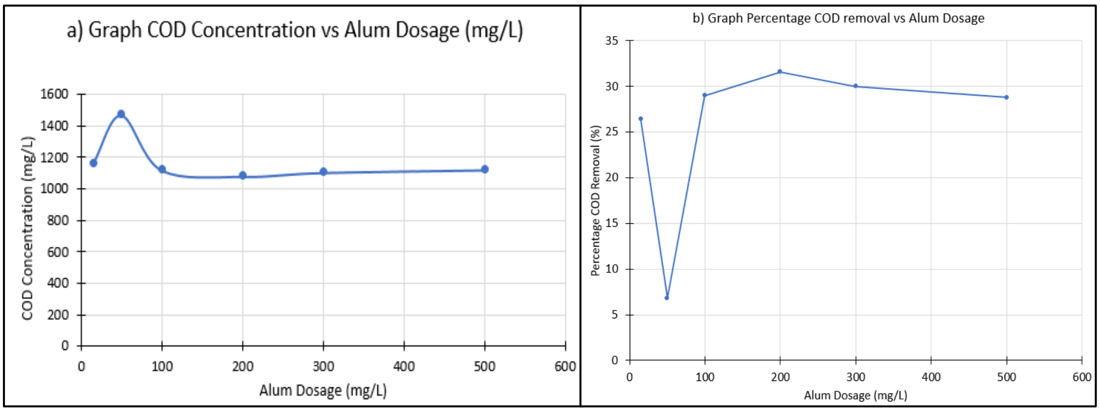


Figure 13: Result of (a) COD value vs Alum Dosage and (b) Percentage Removal of COD vs Alum Dosage

`Based on the line graph for COD in Figure 13, it can be observed that the COD concentration does not vary too much. However, there was a slight decrease at an alum dosage of 200 mg/L. The highest COD removal was 31.6%, which occurred at an alum dosage of 200 mg/L, while the lowest COD removal was 6.8% at an alum dosage of 50 mg/L. However, all the effluent COD levels still do not meet the standard B discharge limit of 200 mg/L. Table 19 shows the average effluent COD concentration throughout the study period for each pH and the average COD removals.

Table 19: Averaged COD Removals

Alum Dosages (mg/L)	Average COD removal (%)
15	26.4
50	6.8
100	29
200	31.6
300	30
500	28.8

4.2.2.2 Effluent Turbidity Results throughout the Study

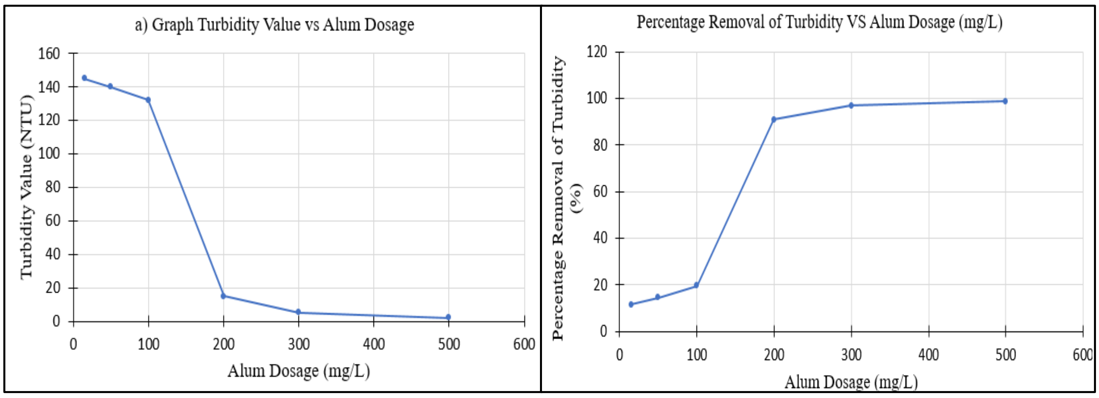


Figure 14: Result of (a) Turbidity value vs Alum Dosage and (b) Percentage Removal of Turbidity vs Alum Dosage

From Figure 14, it can be observed a decrease at alum dosage 200 mg/L, 300 mg/L, and 500 mg/L. The highest turbidity removal was 98.7% which at alum dosage 500 mg/L while the lowest turbidity removal was 11.6% at alum dosage 15 mg/L. Based on the results of the final turbidity concentration, there were only slightly changes. Table 20 shows the average effluent turbidity removals throughout the study period for each alum dosage.

Table 20: Averaged Turbidity Removals

Alum Dosage (mg/L)	Average turbidity removal (%)
15	11.6
50	14.6
100	19.5
200	90.9
300	96.9
500	98.7

4.2.2.3 Effluent Total Suspended Solid (TSS) Results throughout the Study

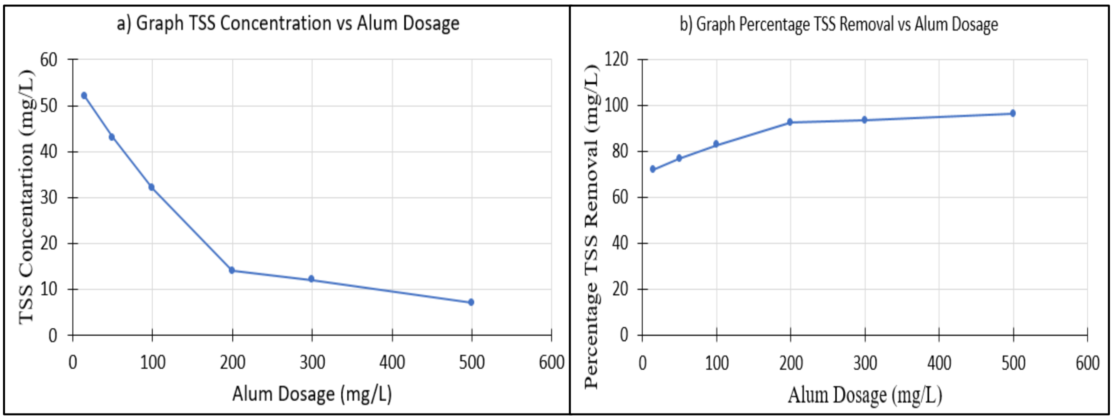


Figure 15: Effluent (a) Total Suspended Solid (TSS) vs pH and (b) Percentage TSS Removal vs pH

From Figure 15a, a decrease in TSS concentration is observed from alum dosage of 15 mg/L to 500 mg/L. The highest TSS removal, 96.2%, occurs at alum dosage 500 mg/L, whereas the lowest removal, 71.9%, is observed at alum dosage 15 mg/L. These results indicate that alum dosage 500 mg/L are highly efficient in removing TSS, meeting the standard A discharge limit for industrial wastewater which is 120 mg/L. Table 21 presents the average TSS removals throughout the study period.

Table 21: Average TSS removal

Alum Dosage (mg/L)	Average TSS removal (%)
15	71.9
50	76.8
100	82.7
200	92.4
300	93.5
500	96.2

4.2.2.4 Effluent Nitrate-Nitrogen Results throughout the Study

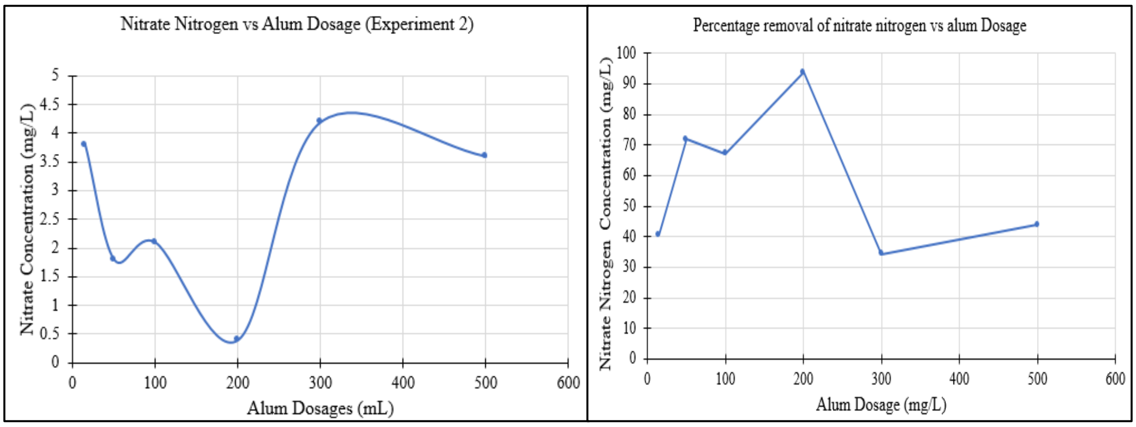


Figure 16: (a) Effluent Nitrate Nitrogen vs Alum Dosage and (b) Percentage removal of nitrate nitrogen vs Alum Dosage

From Figure 16, it can be observed a lowest decreasing at alum dosage 200 mg/L, but there was a slightly increases at alum dosage 300 mg/L and 500 mg/L with average nitrate concentration of 4.2 mg/L, and 3.6 mg/L respectively. The highest nitrate removal was 93.8% which at alum dosage 200 mg/L. Each value was meeting standard A of 20mg/L. Table 22 shows the average nitrate removals throughout the study period for each alum dosage.

Table 22: Average Nitrate Removals

Alum Dosage (mg/L)	Average nitrate removal (%)
15	40.6
50	71.9
100	67.2
200	93.8
300	34.4
500	43.8

4.2.2.5 Effluent Ammonia-Nitrogen Results throughout the Study

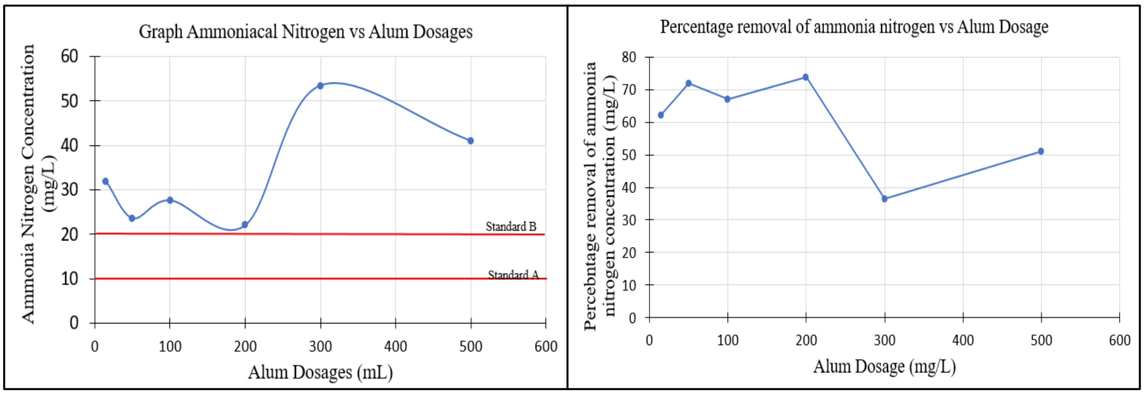


Figure 17: Effluent (a) Ammonia Nitrogen vs Alum Dosage and (b) Percentage Removal of Ammonia Nitrogen vs Alum Dosages

From Figure 17, the highest ammonia removal, 73.8%, occurs at alum dosage 200 mg/L, whereas the lowest removal, 36.4%, is observed at alum dosage 300 mg/L. These results indicate that alum dosage 200 mg/L are highly efficient in removing ammonia. However, the result for alum dosage 200 mg/L was slightly above the standard B discharge limit. Table 23 presents the average ammonia removals throughout the study period for each alum dosage.

Table 23: Average Percentage Ammonia Removal

Alum Dosage (mg/L)	Average ammonia removal (%)
15	62.1
50	71.9
100	67.1
200	73.8
300	36.4
500	51.1

4.2.2.6 Effluent Total Phosphorus Results throughout the Study

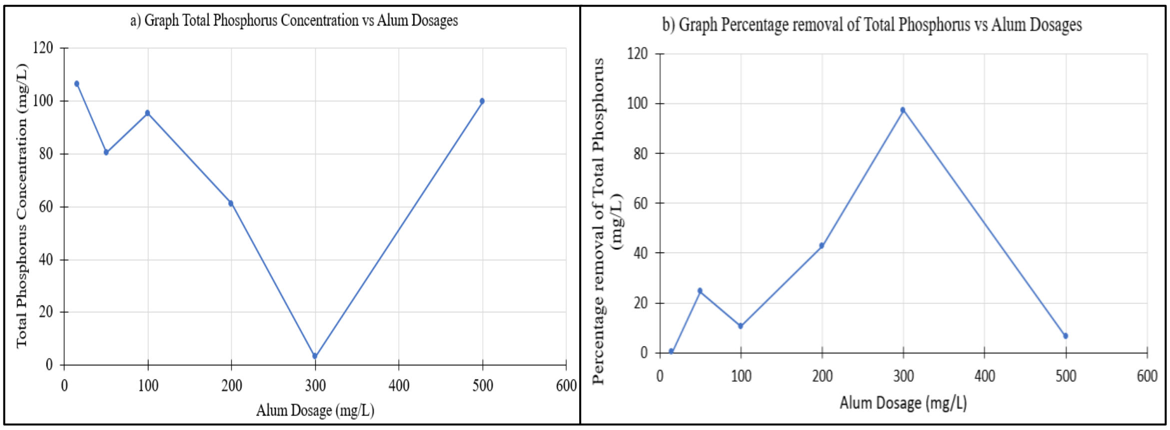


Figure 18: Effluent (a) Total Phosphorus Concentration vs Alum Dosage and (b) Percentage Removal of Total Phosphorus vs Alum Dosages

From Figure 18, a decrease in total phosphorus concentration is observed from alum dosage 100 mg/L to 300 mg/L, while there is a huge increase at alum dosage 500 mg/L. The highest total phosphorus removal, 97.2%, occurs at alum dosage 300 mg/L, whereas the lowest removal, 6.4%, is observed at alum dosage 500 mg/L with average value of 99.6 mg/L. These results indicate that alum dosage 300 mg/L is highly efficient in removing total phosphorus and meet the standard A discharge limit of 10 mg/L for industrial wastewater. Table 24 shows the average total phosphorus removals throughout the study period for each pH.

Table 24: Average Total Phosphorus removal

Alum Dosage (mg/L)	Average total phosphorus removal (%)
15	0.2
50	24.4
100	10.5
200	42.7
300	97.2
500	6.4

4.2.3 Results of Experiment 3: Varying the pH of Electronic Wastewater and Fixed Alum Dosage at 100 mg/L

4.2.3.1 Effluent COD Results throughout the Study

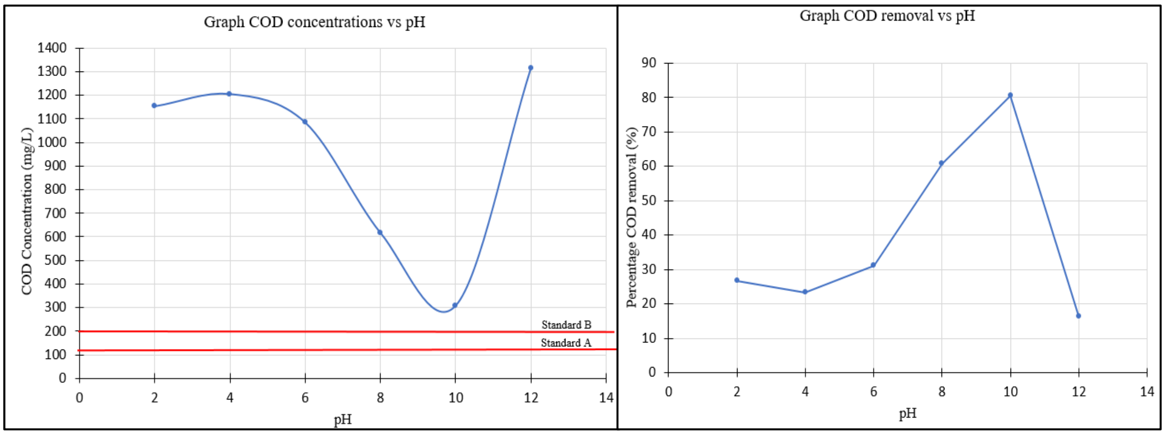


Figure 19: Result of (a) COD concentration vs pH, and (b) COD removal vs pH

Based on the line graph for COD in Figure 19, it is evident that the COD concentration decreases from pH 6 to pH 8 and further to pH 10, with average values of 1085 mg/L, 617 mg/L, and 307 mg/L, respectively. However, there is a slight increase at pH 12 with average concentration of 1314 mg/L. The highest COD removal, at 80.5%, occurs at pH 10 with an average value of 307 mg/L, while the lowest COD removal, at 16.5%, is observed at pH 12 with an average value of 1314 mg/L. Nevertheless, all effluent COD levels still exceed the standard B discharge limit of 200 mg/L. Therefore, the treatment of electronic wastewater needs to be continued with biological treatment system which is high-rate aeration system in order to ensure COD is within the limit.

Table 25 presents the average COD removal rates throughout all pH.

Table 25: Averaged COD Removals

pH	Average COD removal (%)
2	26.7
4	23.4
6	31.1
8	60.8
10	80.5
12	16.5

4.2.3.2 Effluent Turbidity Results throughout the Study

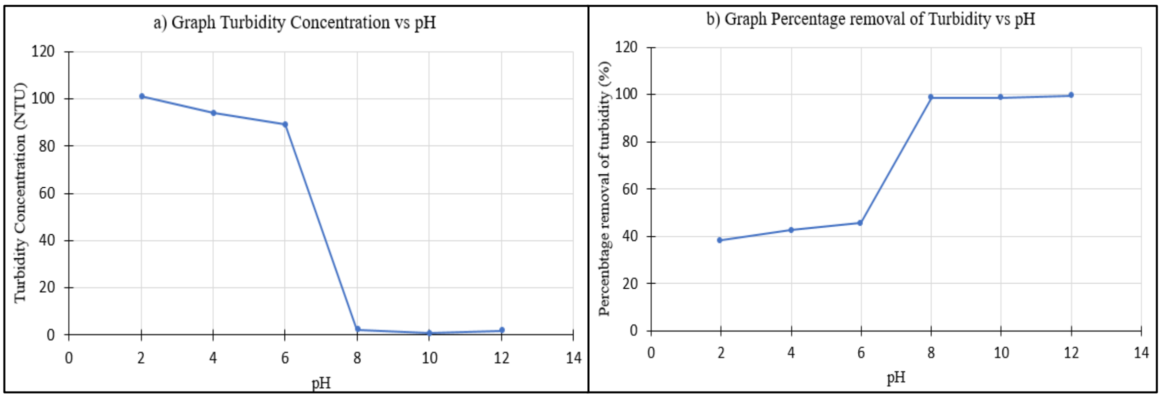


Figure 20: Result of (a) Turbidity value vs pH and (b) Percentage Removal of Turbidity vs pH

From Figure 20, it can be observed a decrease concentration of turbidity at pH 8, pH 10, and pH 12. The highest turbidity removal was 99.5% which at pH 10, while the lowest turbidity removal was 38.4% at pH 2. Based on the results of the final turbidity concentration, pH 10 is the optimum pH for turbidity removal. Table 26 shows the average effluent turbidity value throughout the study period for each pH and the average turbidity removals.

Table 26: Averaged Turbidity Removals

pH	Average turbidity removal (%)
2	38.4
4	42.6
6	45.7
8	98.6
10	99.5
12	98.8

4.2.3.2 Effluent Total Suspended Solid (TSS) Results throughout the Study

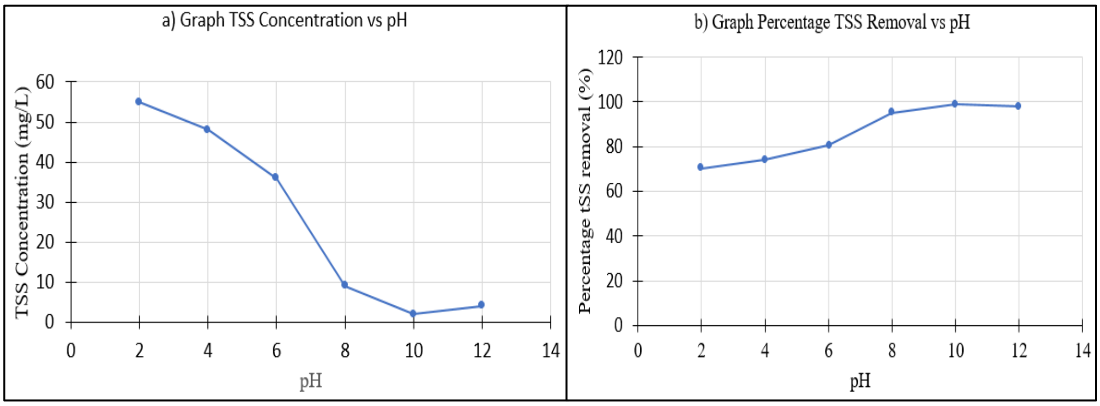


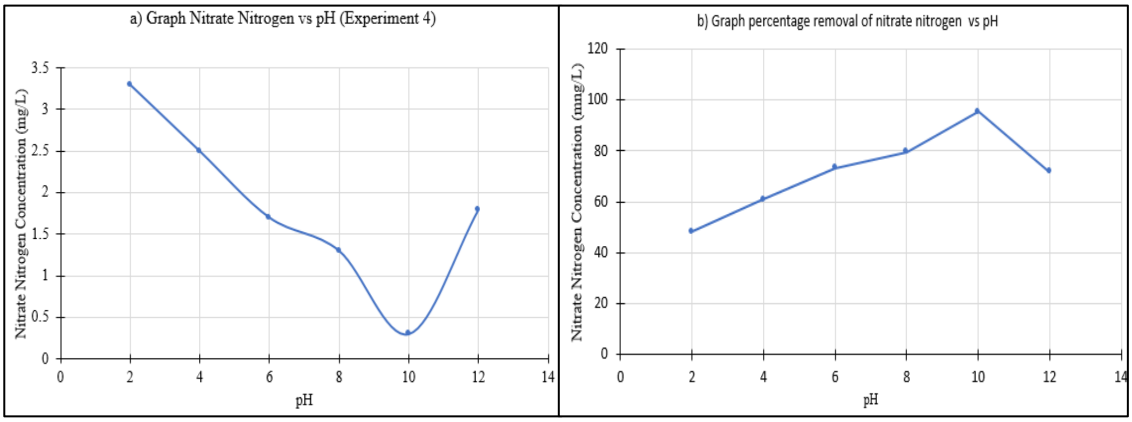
Figure 21: Effluent (a) Total Suspended Solid (TSS) vs pH and (b) Percentage TSS Removal vs pH

From Figure 21a, a decrease in TSS concentration is observed from pH 6, pH 8, pH 10, and pH 12, with average TSS concentration of 36 mg/L, 9 mg/L, 2 mg/L, and 4 mg/L, respectively. The highest TSS removal was, 98.9%, occurs at pH 10 whereas the lowest removal, 70.3%, is observed at pH 2. These results indicate that pH 10 is highly efficient in removing TSS, meeting the standard A discharge limit for industrial wastewater which is 120 mg/L. Table 27 presents the average effluent TSS concentrations throughout the study period for each pH and the corresponding average TSS removals.

Table 27: Average Effluent TSS/TSS removal

pH	Average Percentage TSS removal (%)
2	70.3
4	74.1
6	80.5
8	95.1
10	98.9
12	97.8

4.2.3.3 Effluent Nitrate-Nitrogen Results throughout the Study


a) Graph Nitrate Nitrogen vs pH (Experiment 4)

b) Graph percentage removal of nitrate nitrogen vs pH

Figure 22: (a) Effluent Nitrate Nitrogen vs pH and (b) Percentage removal of nitrate nitrogen vs pH

From Figure 22, it can be observed a nitrate nitrogen concentration were decreasing from pH 2 to pH 12, with average nitrate nitrogen concentration of 3.3 mg/L, 2.5 mg/L, 1.7 mg/L, 1.3 mg/L, 0.3 mg/L, respectively. However, there was a slightly increases at pH 12 with average nitrate nitrogen concentration of 1.8 mg/L. The highest nitrate removal was 95.3% which at pH 10. Each value was meeting standard A of 20mg/L, therefore, pH 10 is the optimum pH fpr nitrate nitrogen removal. Table 28 shows the average effluent nitrate concentration throughout the study period for each alum dosage and the average nitrate removals.

Table 28: Average Nitrate Nitrogen Removals

pH	Average percentage of nitrate removal (%)
2	48.4
4	60.9
6	73.4
8	79.6
10	95.3
12	71.8

4.2.3.4 Effluent Ammonia-Nitrogen Results throughout the Study

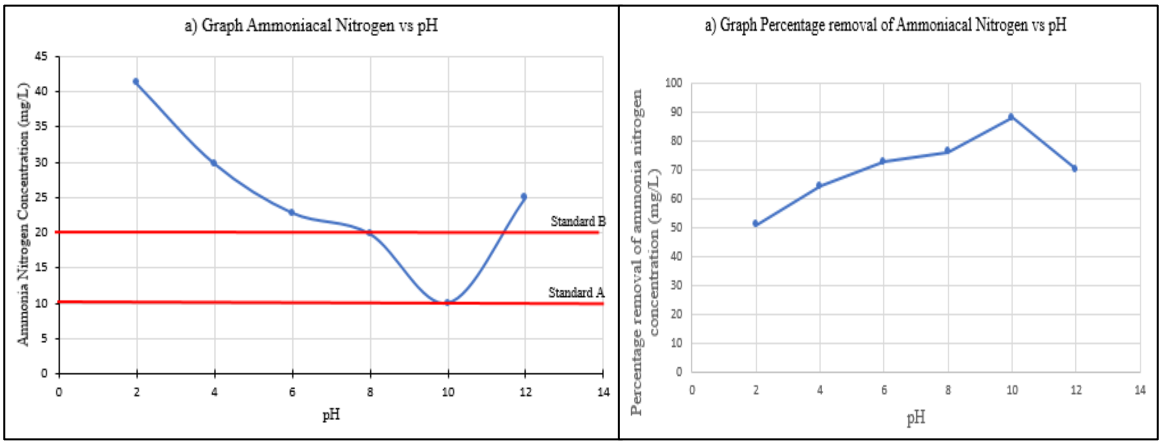


Figure 23: Effluent (a) Ammonia Nitrogen vs pH and Percentage Removal of Ammonia Nitrogen vs pH

From Figure 23, the highest ammonia removal concentration were steadily decreasing from pH 2. pH 4, pH 6, pH 8, and pH 10, with average ammonia nitrogen concentration of 41.2 mg/l, 29.8 mg/L, 22.8 mg/L, 19.8 mg/L, and 10 mg/L, respectively. The highest removal of ammonia nitrogen was occurred at pH 10, which is 88.1%. Whereas the lowest removal, 51%, is observed at pH 2. These results indicate that pH 10 are highly efficient in removing ammonia and is was within standard A discharge limit. Table 29 presents the average effluent ammonia concentrations and the corresponding average ammonia removals throughout the study period for each pH.

Table 29: Average Ammonia Nitrogen Removal

pH	Percentage ammonia removal (%)
2	51
4	64.5
6	72.9
8	76.4
10	88.1
12	70.2

4.2.3.5 Effluent Total Phosphorus Results throughout the Study

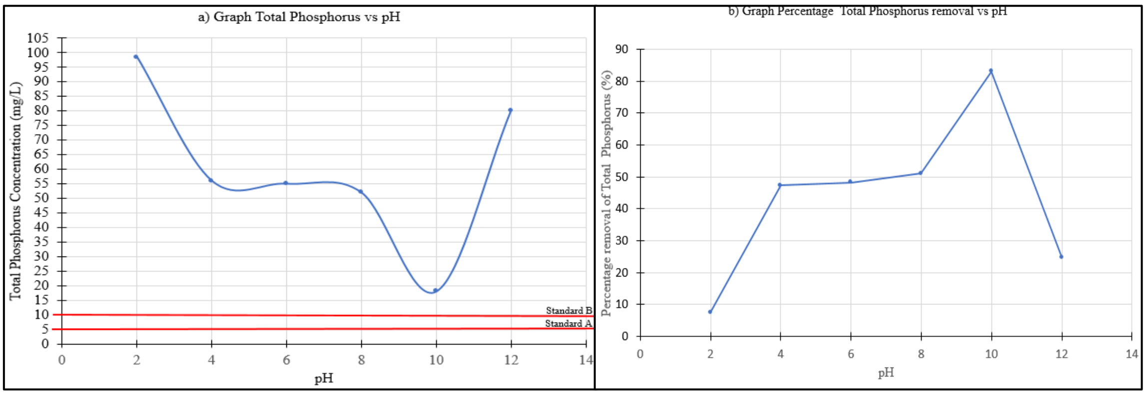


Figure 24: Effluent (a) Total Phosphorus Concentration vs pH and Percentage Removal of Total Phosphorus vs pH

From Figure 24, a decrease in total phosphorus concentration is observed from pH 6, pH 8, and pH 10 with average total phosphorus concentration of 55 mg/L, 52 mg/L, and 18 mg/L while there is a huge increase at pH 12 with average total phosphorus concentration of 80 mg/L. The highest total phosphorus removal, 83.1%, occurs at pH 10, whereas the lowest removal, 7.5%, is observed at pH 2 with average concentration of 98.4 mg/L. These results indicate that pH 10 is highly efficient in removing total phosphorus. However, the concentration does not meet the standard B discharge limit of 10 mg/L for industrial wastewater. Therefore, further treatment using biological treatment system is required to reduce the Total Phosphorus concentration. Table 30 shows the average effluent total phosphorus concentration throughout the study period for each pH and the percentage total phosphorus removals.

Table 30: Average Effluent Total Phosphorus Concentration/Total Phosphorus removal

pH	Percentage total phosphorus removal (%)
2	7.5
4	47.4
6	48.3
8	51.1
10	83.1
12	24.8

4.2.4 Results of Experiment 4: Varied the Ferric Chloride Dosage of Electronic Wastewater

4.2.4.1 Effluent COD Results throughout the Study

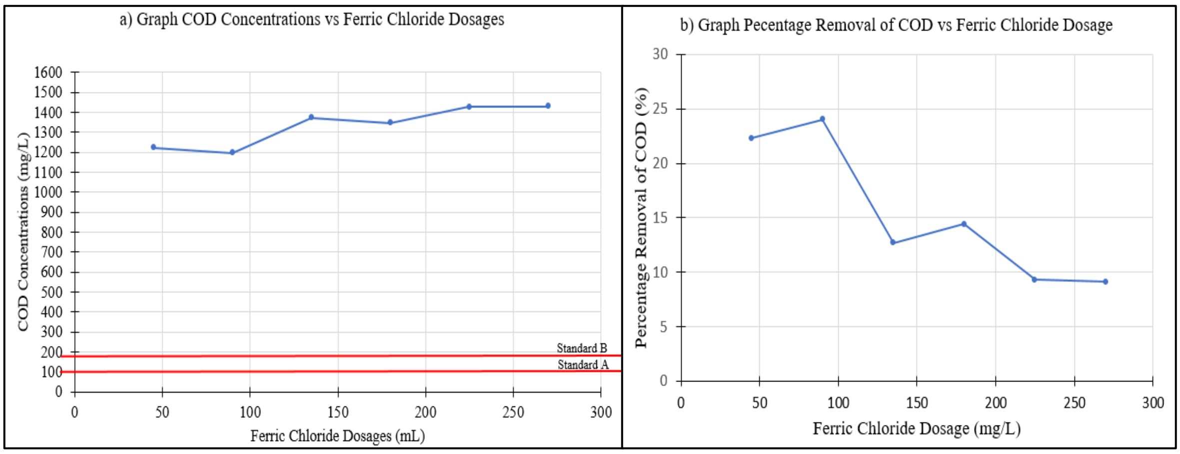


Figure 25: Result of (a) COD concentration vs Ferric Chloride Dosage, and (b) COD removal vs Ferric Chloride Dosage

Based on the line graph for COD in Figure 25, it shows that the COD concentration increases with the ferric chloride (FeCL) dosages. However, there is a slight decrease at FeCL dosage of 90 mg/L which is the highest COD removal, at 24%. The lowest COD removal, at 9.1%, is observed at ferric chloride dosage of 270 mg/L with an average concentration of 1430 mg/L. Nevertheless, all effluent COD levels still exceed the standard B discharge limit of 200 mg/L. Table 31 presents the average COD removal rates throughout the study period for each ferric chloride dosages

Table 31: Averaged Effluent COD Concentration /COD Removals

Ferric Chloride Dosages	Percentage COD removal (%)
45	22.3
90	24
135	12.7
180	14.4
225	9.3
270	9.1

4.2.4.2 Effluent Turbidity Results throughout the Study

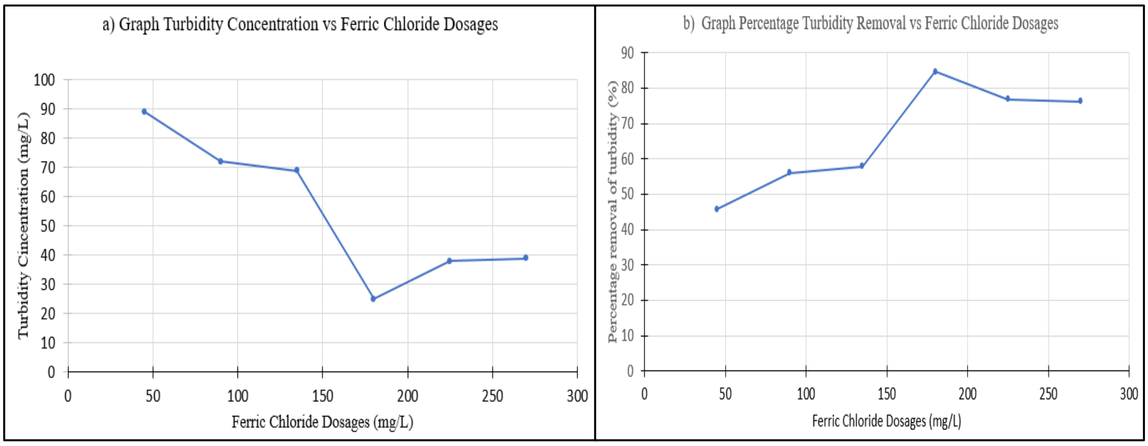


Figure 26: Result of (a) Turbidity value vs pH and (b) Percentage Removal of Turbidity vs pH

From Figure 26, it can be observed that the turbidity concentration is steadily decrease from Ferric Chloride dosage of 90 mg/L, 135 mg/L, and 180 mg/L, with average turbidity of 72 NTU, 69 NTU, and 25 NTU, respectively. The highest turbidity removal was 84.7% which at ferric chloride dosage of 180 mg/L, while the lowest turbidity removal was 45.7% at ferric chloride dosage of 45 mg/L. Table 32 shows the average turbidity removals throughout the study period for each pH.

Table 32: Averaged Turbidity Removals

Ferric Chloride Dosages	Average turbidity removal (%)
45	45.7
90	56.1
135	57.9
180	84.7
225	76.8
270	76.2

4.2.4.3 Effluent Total Suspended Solid (TSS) Results throughout the Study

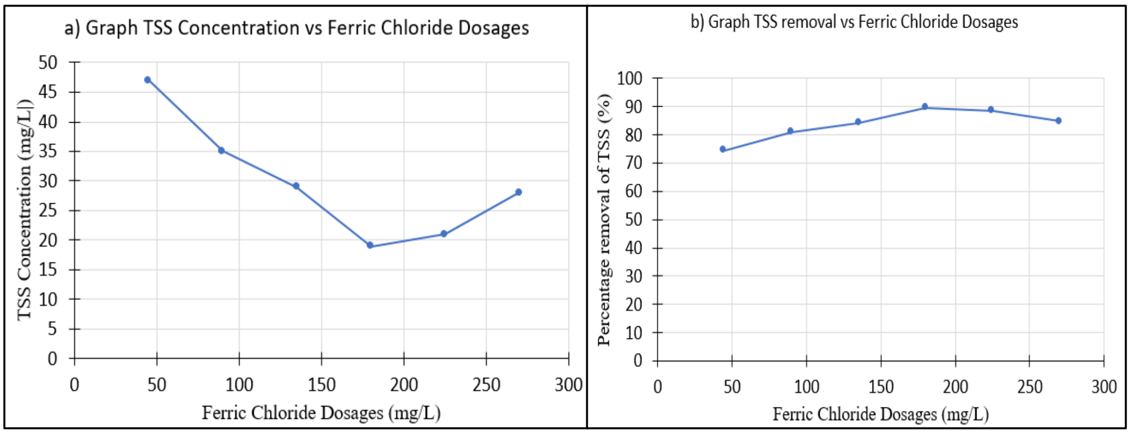


Figure 27: Effluent (a) Total Suspended Solid (TSS) vs Ferric Chloride Dosages and (b) Percentage TSS Removal vs Ferric Chloride Dosages

From Figure 27, a decrease in TSS concentration is observed from ferric chloride dosages of 90 mg/L, 135 mg/L, and 180 mg/L, with average TSS concentration of 35 mg/L, 29 mg/L, and 19 mg/L, respectively. The highest TSS removal was, 89.7%, occurs at ferric chloride dosage of 180 mg/L whereas the lowest removal, 74.6%, is observed ferric chloride dosage of 45 mg/L. These results indicate that ferric chloride dosage of 180 mg/L is highly efficient in removing TSS, meeting the standard A discharge limit for industrial wastewater which is 120 mg/L. Table 33 presents the average effluent TSS removals throughout the study period for each ferric chloride dosages.

Table 33: Average TSS removal

Ferric Chloride Dosages	Average Percentage TSS removal (%)
45	74.6
90	81.1
135	84.3
180	89.7
225	88.6
270	84.9

4.2.4.4 Effluent Nitrate-Nitrogen Results throughout the Study

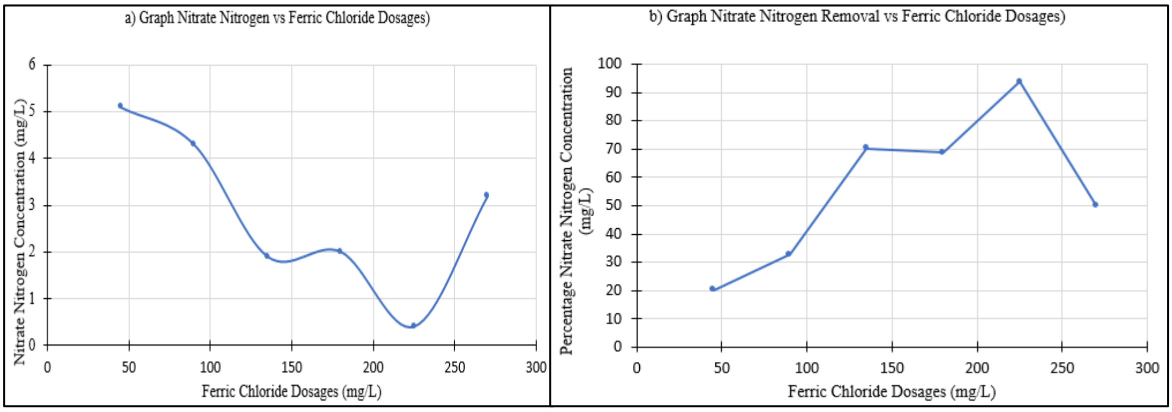


Figure 28: (a) Effluent Nitrate Nitrogen vs Ferric Chloride Dosages and (b) Percentage removal of nitrate nitrogen vs Ferric Chloride Dosages

From Figure 28, it can be observed a nitrate nitrogen concentration were decreasing from ferric chloride dosages of 90 mg/L to 135 mg/L, and slightly increase at 180 mg/L, with average TSS concentration of 4.3 mg/L, 1.9 mg/L, and 3 mg/L, respectively. The highest nitrate removal was 93.8% which at ferric chloride dosage of 225 mg/L. Each ferric chloride dosages were meeting standard A of 20mg/L. Table 34 shows the average effluent nitrate concentration throughout the study period for each alum dosage and the average nitrate removals.

Table 34: Average Effluent Nitrate/Nitrate Removals

Ferric Chloride Dosages	Average percentage of nitrate removal (%)
45	20.3
90	32.8
135	70.3
180	68.8
225	93.8
270	50.0

4.2.4.5 Effluent Ammonia-Nitrogen Results throughout the Study

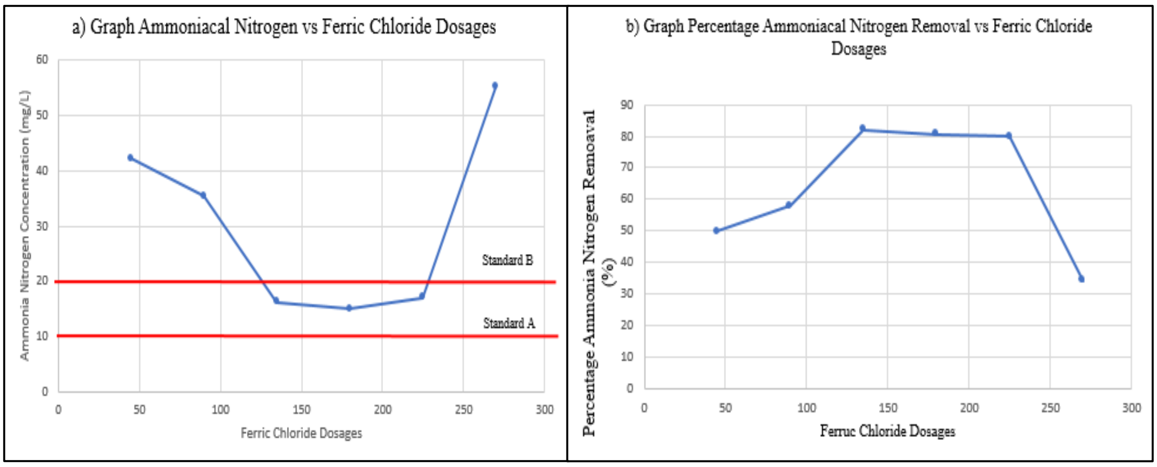


Figure 29: Effluent (a) Ammonia Nitrogen vs Ferric Chloride Dosages and (b) Percentage Removal of Ammonia Nitrogen vs Ferric Chloride Dosages

From Figure 29, the highest ammonia removal concentration was steadily decreasing from ferric chloride dosages of 90 mg/L to 225 mg/L with average ammonia nitrogen concentration of 35.4 mg/l, 16.2 mg/L, 15.0 mg/L, and 17.0 mg/L, respectively. The highest removal of ammonia nitrogen was occurred at ferric chloride dosages of 135 mg/L, which is 82.1%. Whereas the lowest removal, 34.3%, is observed at ferric chloride dosages of 270 mg/L. These results indicate that ferric chloride dosages of 136 mg/L are highly efficient in removing ammonia. However, it is not within standard B discharge limit. Table 35 presents the average effluent ammonia concentrations throughout the study period for each pH and the corresponding average ammonia removals.

Table 35: Average Effluent Ammonia/Ammonia Removal

Ferric Chloride Dosages	Percentage ammonia removal (%)
45	49.8
90	57.9
135	82.1
180	80.7
225	79.8
270	34.3

4.2.4.6 Effluent Total Phosphorus Results throughout the Study

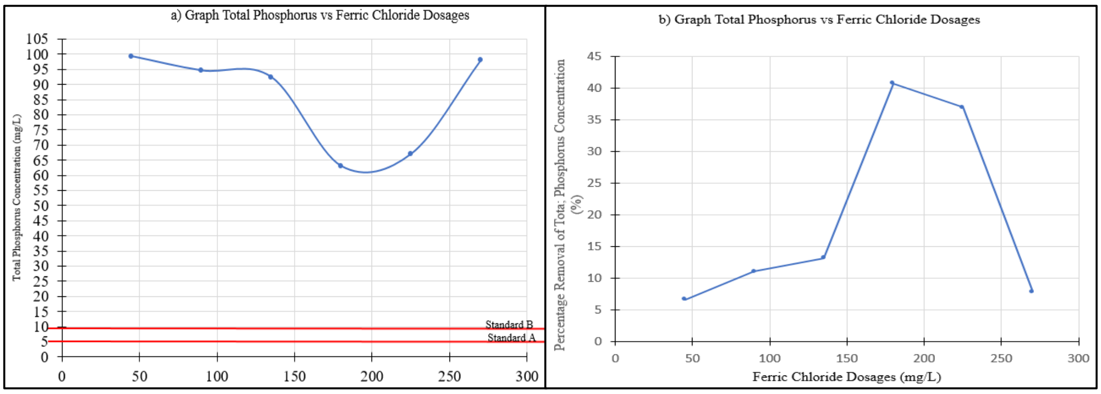


Figure 30: Effluent (a) Total Phosphorus (TP) Concentration vs Ferric Chloride Dosages and (b) Percentage Removal of TP vs Ferric Chloride Dosages

From Figure 30, a decrease in total phosphorus concentration is observed from ferric chloride dosages of 90 mg/L, 135 mg/L, and 180 mg/L with average total phosphorus concentration of 94.6 mg/L, 92.4 mg/L, and 63 mg/L. The highest total phosphorus removal, 40.8%, occurs at ferric chloride dosage of 180 mg/L, whereas the lowest removal, 6.7%, is observed at ferric chloride dosage of with average concentration of 99.3 mg/L. These results indicate that ferric chloride dosage of 180 mg/L was efficient in removing total phosphorus. However, the concentration does not meet the standard B discharge limit of 10 mg/L for industrial wastewater. Therefore, further treatment using biological treatment system is required to reduce the Total Phosphorus concentration. Table 36 shows the average percentage total phosphorus removals throughout the study period for each dosages.

Table 36: Average Effluent Total Phosphorus Concentration/Total Phosphorus removal

Ferric Chloride Dosages	Percentage total phosphorus removal (%)
45	6.7
90	11.1
135	13.2
180	40.8
225	37
270	7.9

4.2.5 Results of Experiment 5: Varied the pH of Electronic Wastewater, Fixed Ferric Chloride Dosage of 180 mg/L

4.2.5.1 Effluent COD Results throughout the Study

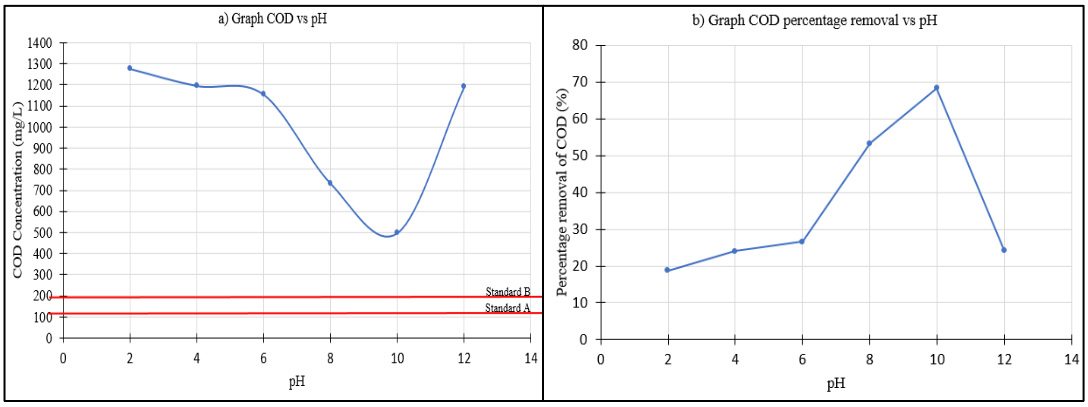


Figure 31: Result of (a) COD concentration vs pH, and (b) COD removal vs pH

Based on the line graph for COD in Figure 31, it is evident that the COD concentration decreases from pH 2 to pH 10, with COD concentrations of 1278 mg/L, 1197 mg/L, 1156 mg/L, 734 mg/L, and 498 mg/L, respectively. However, the COD concentration increases at pH 12. The lowest COD removal, at 18.8%, is observed at pH 2, while the highest removal of COD, at 68.4%, occurs at pH 10. Nevertheless, all effluent COD levels still exceed the standard B discharge limit of 200 mg/L. Table 37 presents the average effluent COD concentration throughout the study period for each pH and the corresponding average COD removal rates.

Table 37: Averaged Effluent COD Concentration /COD Removals

pH	Percentage COD removal (%)
2	18.8
4	24
6	26.6
8	53.3
10	68.4
12	24.3

4.2.5.2 Effluent Turbidity Results throughout the Study

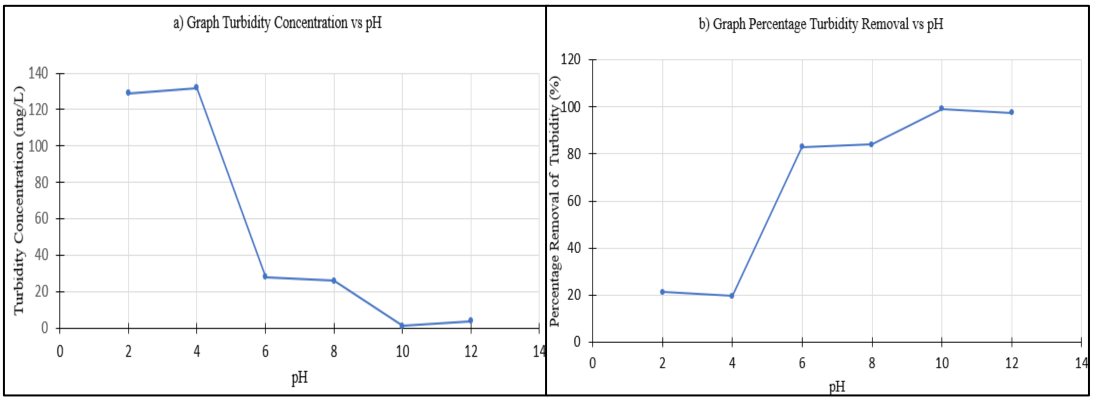


Figure 32: Result of (a) Turbidity value vs pH and (b) Percentage Removal of Turbidity vs pH

From Figure 32, it can be observed that the turbidity concentration is steadily decrease from pH 4 to pH 10 with average turbidity value of 132 NTU, 28 NTU, 26 NTU, and 1.42 NTU, respectively. The highest turbidity removal was 99.1% which at pH 10, while the lowest turbidity removal was 19.5 % at pH 4. Table 38 shows the average turbidity removals for each pH.

Table 38: Averaged Effluent Turbidity/Turbidity Removals

pH	Average turbidity removal (%)
2	21.3
4	19.5
6	82.9
8	84.1
10	99.1
12	97.6

4.2.5.3 Effluent Total Suspended Solid (TSS) Results throughout the Study

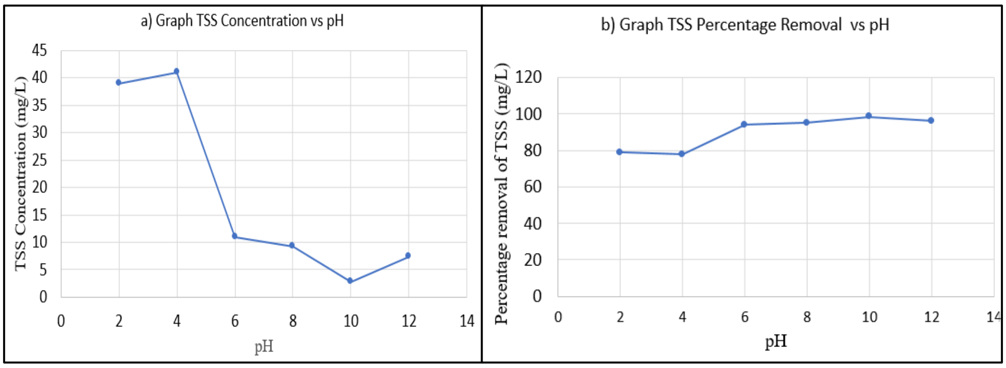


Figure 33: Effluent (a) Total Suspended Solid (TSS) vs pH Dosages and (b) Percentage TSS Removal vs pH

From Figure 33, a decrease in TSS concentration is observed from pH 6 to pH 10 with average TSS concentration of 11 mg/L, 9.3 mg/L, and 2.8 mg/L, respectively. The highest TSS removal was, 98.5% occurs at pH 10 whereas the lowest removal, 77.8% is observed at pH 4. These results indicate that pH 10 is highly efficient in removing TSS, meeting the standard A discharge limit for industrial wastewater which is 120 mg/L. Table 39 presents the average TSS removal throughout the study period for each pH.

Table 39: Average Effluent TSS/TSS removal

pH	Average Percentage TSS removal (%)
2	78.9
4	77.8
6	94.1
8	95
10	98.5
12	96

4.2.5.4 Effluent Nitrate-Nitrogen Results throughout the Study

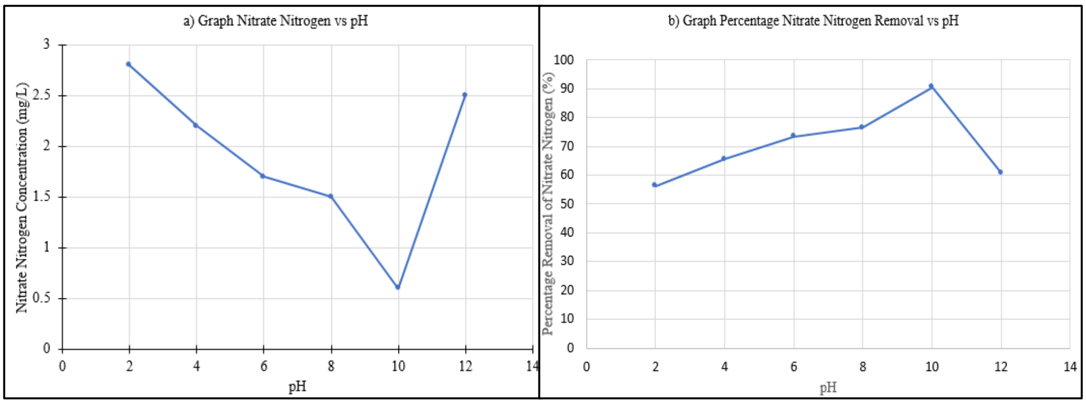


Figure 34: (a) Effluent Nitrate Nitrogen vs pH and (b) Percentage removal of nitrate nitrogen vs pH

From Figure 34, it can be observed a nitrate nitrogen concentration were decreasing from pH 4 to pH 10, with average nitrate nitrogen concentration of 2.2 mg/L, 1.7 mg/L, 1.5 mg/L, and 0.6 mg/L, respectively. However, there was slightly increase at pH 12, with average TSS concentration of 2.5 mg/L. The highest nitrate removal was 90.6% which at pH 10. Each pH was meeting standard A of 20mg/L. Table 40 shows the average effluent nitrate concentration throughout the study period for each alum dosage and the average nitrate removals.

Table 40: Average Effluent Nitrate/Nitrate Removals

pH	Average percentage of nitrate removal (%)
2	56.3
4	65.6
6	73.4
8	76.6
10	90.6
12	60.9

4.2.5.5 Effluent Ammonia-Nitrogen Results throughout the Study

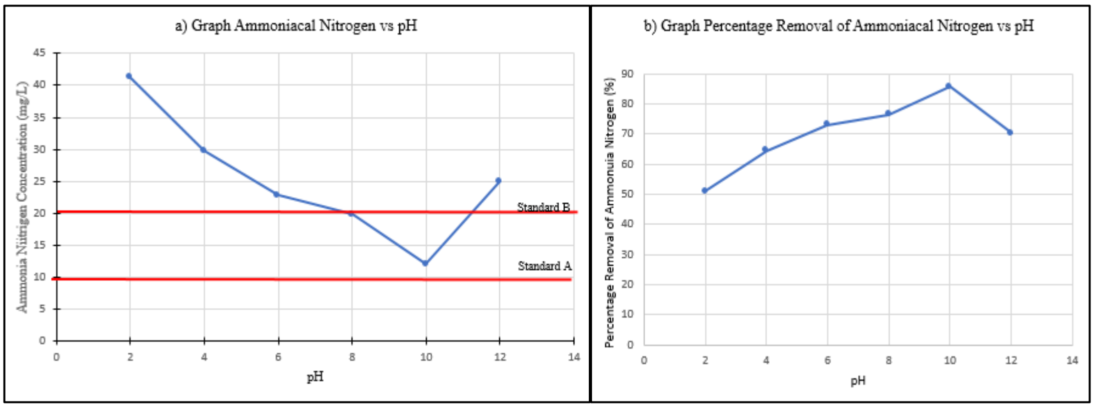


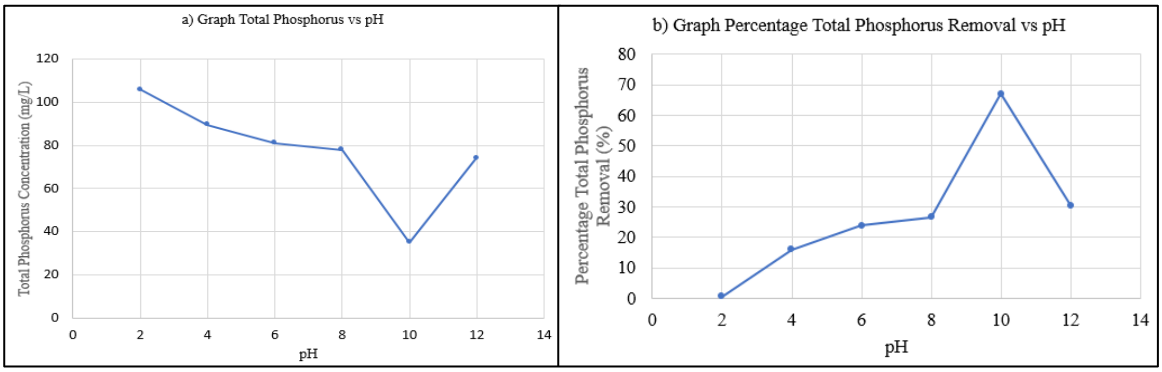
Figure 35: Effluent (a) Ammonia Nitrogen vs pH and (b) Percentage Removal of Ammonia Nitrogen vs pH

From Figure 35, the ammonia removal concentration was steadily decreasing from pH 2, pH 4, pH 6, pH 8, and pH 10, with average ammonia nitrogen concentration of 41.2 mg/l, 29.8 mg/L, 22.8 mg/L, 19.8 mg/L, and 12 mg/L, respectively. The highest removal of ammonia nitrogen was occurred at pH 10, which is 85.7%. Whereas the lowest removal, 50.9%, is observed at pH 2. These results indicate that pH 10 are highly efficient in removing ammonia and it was within standard B discharge limit. Table 41 presents the average ammonia removals throughout the study period for each pH.

Table 41: Average Ammonia Removal

pH	Percentage ammonia removal (%)
2	50.9
4	64.5
6	72.9
8	76.4
10	85.7
12	70.2

4.2.5.6 Effluent Total Phosphorus Results throughout the Study


a) Graph Total Phosphorus vs pH

b) Graph Percentage Total Phosphorus Removal vs pH

Figure 36: Effluent (a) Total Phosphorus Concentration vs pH and (b) Percentage Removal of Total Phosphorus vs pH

From Figure 36, a decrease in total phosphorus concentration is observed from pH 4 to pH 10 with average total phosphorus concentration of 89.4 mg/L, 81 mg/L,78 mg/L, and 35 mg/L, respectively. The highest total phosphorus removal, 67.1%, occurs at pH 10, whereas the lowest removal, 0.7%, is observed at pH 2 with average concentration of 105.7 mg/L. These results indicate that pH 10 was efficient in removing total phosphorus. However, the concentration does not meet the standard B discharge limit of 10 mg/L for industrial wastewater. Therefore, further treatment using biological treatment system is required to reduce the Total Phosphorus concentration. Table 42 shows the average total phosphorus removal throughout the study period for each pH.

Table 42: Average Total Phosphorus removal

pH	Percentage total phosphorus removal (%)
2	0.7
4	16
6	23.9
8	26.7
10	67.1
12	30.5

4.2.6 Results of Experiment 6: Varied the pH of Electronic Wastewater and Varied Alum-Ferric Coagulant Dosage

4.2.6.1 Effluent COD Results throughout the Study

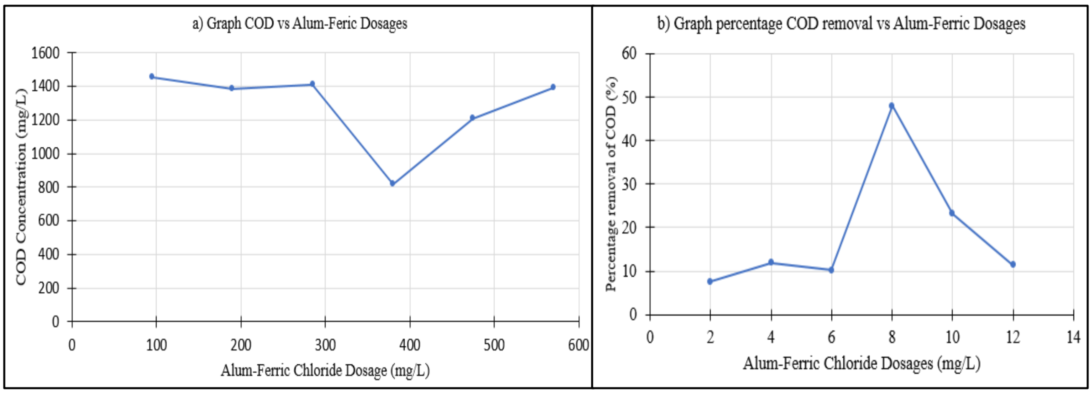


Figure 37: Result of (a) COD concentration vs Alum-Ferric Dosages, and (b) COD removal vs Alum-Ferric Dosages

Based on the line graph for COD in Figure 37, it can be observed that the COD concentration decreases from alum-ferric dosages 285 mg/L to 380 mg/L, with COD concentrations of 1413 mg/L and 820 mg/L, respectively. However, the COD concentration increases at alum-ferric dosages of 465 mg/L and 570 mg/L. The lowest COD removal, at 10.2%, is observed at alum-ferric dosages of 285 mg/L, while the highest removal of COD, at 47.9%, occurs at alum-ferric dosages of 380 mg/L. Nevertheless, all effluent COD levels still exceed the standard B discharge limit of 200 mg/L. Table 43 presents the average effluent COD concentration throughout the study period for each alum-ferric dosages and the corresponding average COD removal rates.

Table 43: Averaged COD Removals

Alum-Ferric Dosages	Percentage COD removal (%)
95	7.6
190	11.9
285	10.2
380	47.9
475	23.1
570	11.4

4.2.6.2 Effluent Turbidity Results throughout the Study

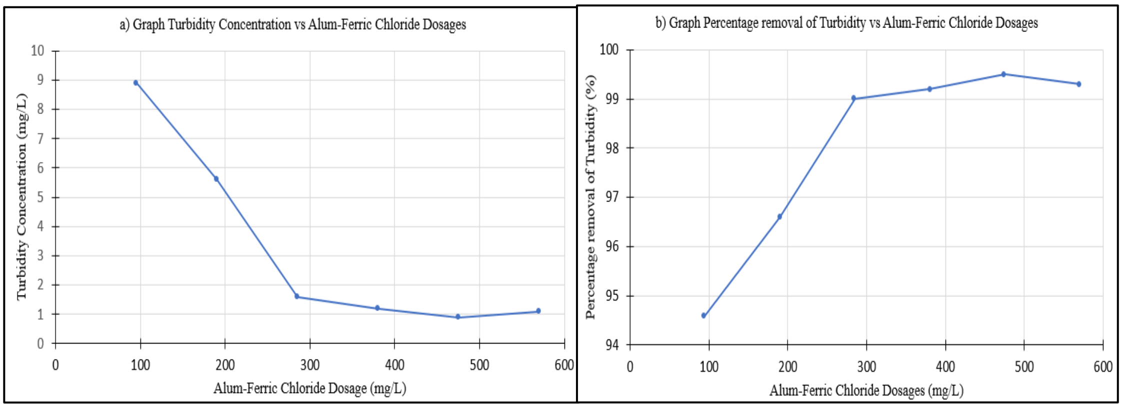


Figure 38: Result of (a) Turbidity value vs Alum-Ferric Dosages and (b) Percentage Removal of Turbidity vs Alum-Ferric Dosages

From Figure 38, it can be observed that the turbidity concentration is steadily decrease from alum-ferric chloride dosages of 95 mg/L to 475 mg/L with average turbidity value of 8.9 NTU, 5.6 NTU, 1.6 NTU, 1.2 NTU, and 0.9 NTU respectively. The highest turbidity removal was 99.5 % which at alum-ferric dosages of 475 mg/L, while the lowest turbidity removal was 94.6 % at alum-ferric dosages of 95 mg/L. Table 44 shows the average effluent turbidity value throughout the study period for each pH and the average turbidity removals.

Table 44: Averaged Turbidity Removals

Alum-Ferric Dosages	Average turbidity removal (%)
95	94.6
190	96.6
285	99
380	99.2
475	99.5
570	99.3

4.2.6.3 Effluent Total Suspended Solid (TSS) Results throughout the Study

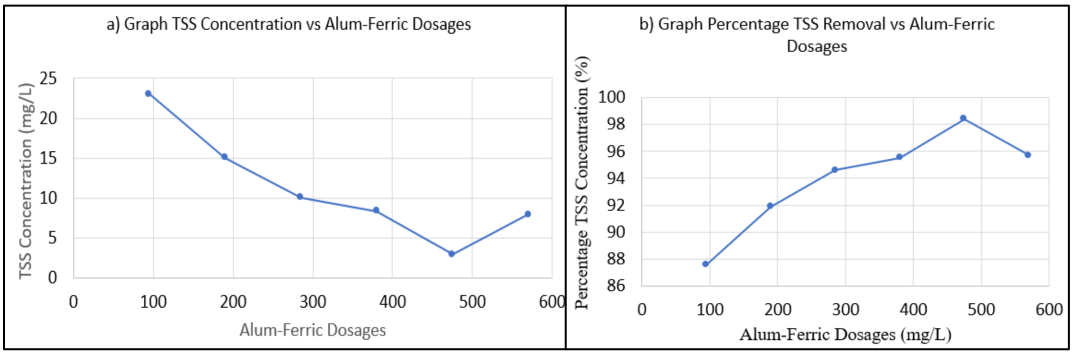


Figure 39: Effluent (a) Total Suspended Solid (TSS) vs Alum-Ferric Dosages and (b) Percentage TSS Removal vs Alum-Ferric Dosages

From Figure 39, a decrease in TSS concentration is observed from alum-ferric chloride dosages of 95 mg/L to 475 mg/L with average TSS concentration of 23 mg/L, 15 mg/L, 10 mg/L, 8.3 mg/L, 2.9 mg/L, and 7.9 mg/L, respectively. The highest TSS removal was, 98.4% occurs at alum-ferric chloride dosages of 475 mg/L whereas the lowest removal, 87.6% is observed at alum-ferric chloride dosages of 95 mg/L. These results indicate that alum-ferric chloride dosages of 475 mg/L is highly efficient in removing TSS, meeting the standard A discharge limit for industrial wastewater which is 120 mg/L. Table 45 presents the average effluent TSS concentrations throughout the study period for each pH and the corresponding average TSS removals.

Table 45: Average TSS removal

Alum-Ferric Dosages	Average TSS Concentration (mg/L)	Average Percentage TSS removal (%)
95	23	87.6
190	15	91.9
285	10	94.6
380	8.3	95.5
475	2.9	98.4
570	7.9	95.7

4.2.6.4 Effluent Nitrate-Nitrogen Results throughout the Study

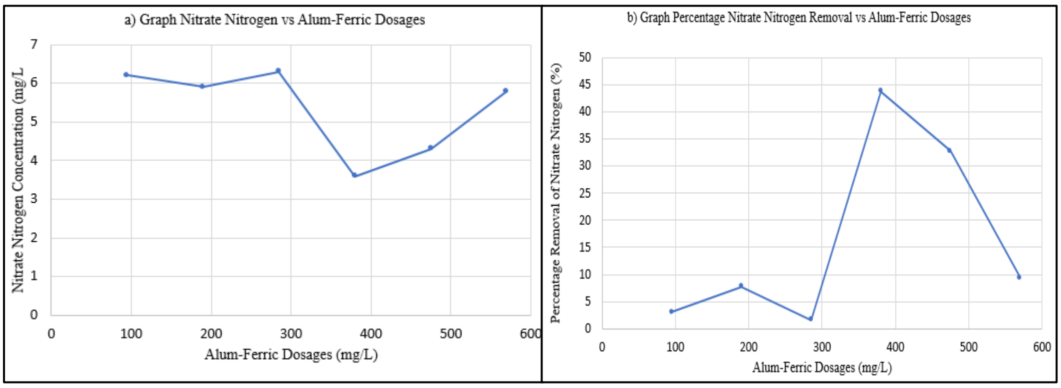


Figure 40: (a) Effluent Nitrate Nitrogen vs Alum-Ferric Dosages and (b) Percentage removal of nitrate nitrogen vs Alum-Ferric Dosages

From Figure 40, it can be observed a nitrate nitrogen concentration were does not vary very much from alum-ferric chloride dosages 95 mg/L, 190 mg/L, 285 mg/L, 380 mg/L, 475 mg/L, and 570 mg/L, with average nitrate nitrogen concentration of 6.2 mg/L, 5.9 mg/L, 6.3 mg/L, 3.6 mg/L, 4.3 mg/L, and 5.8 mg/L respectively. The highest nitrate removal was 43.8% which at alum-ferric dosages of 380 mg/L. Each pH was meeting standard A of 20mg/L. Table 46 shows the average nitrate removals throughout the study period for each alum-ferric concentration dosage.

Table 46: Average Nitrate Removals

Alum-Ferric Dosages	Average percentage of nitrate removal (%)
95	3.1
190	7.8
285	1.6
380	43.8
475	32.8
570	9.4

4.2.6.5 Effluent Ammonia-Nitrogen Results throughout the Study

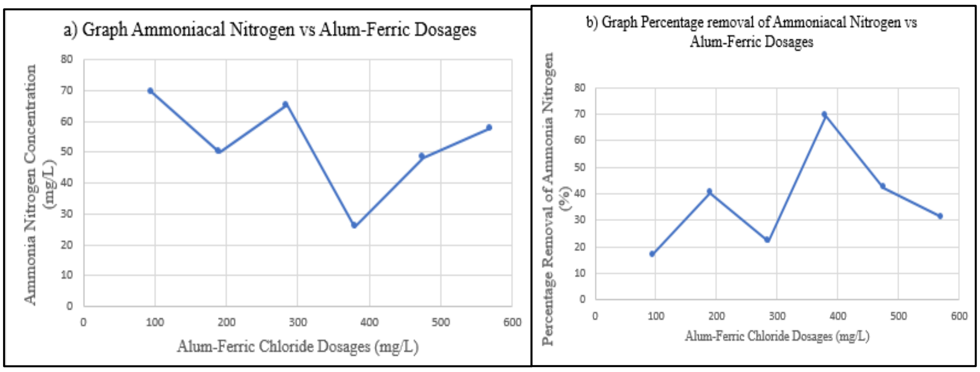


Figure 41: Effluent (a) Ammonia Nitrogen vs Alum-Ferric Dosages and (b) Percentage Removal of Ammonia Nitrogen vs Alum-Ferric Dosages

From Figure 41, the ammonia concentration was decreasing at alum-ferric chloride dosages of 380 mg/L and 190 mg/L, with average ammonia nitrogen concentration of 25.8 mg/L and 50.2 mg/L, respectively. The highest removal of ammonia nitrogen was occurred at alum-ferric chloride dosage of 380 mg/L, which is 69.3%. Whereas the lowest removal, 16.9%, is observed at alum-ferric coagulant dosages of 95 mg/L. Table 47 presents the average ammonia removals throughout the study period for each pH. These results indicate that pH 10 are highly efficient in removing ammonia and it was within standard B discharge limit.

Table 47: Average Ammonia Removal

Alum-Ferric Dosages	Percentage ammonia removal (%)
95	16.9
190	40.2
285	22.1
380	69.3
475	42.4
570	31.2

4.2.6.6 Effluent Total Phosphorus Results throughout the Study

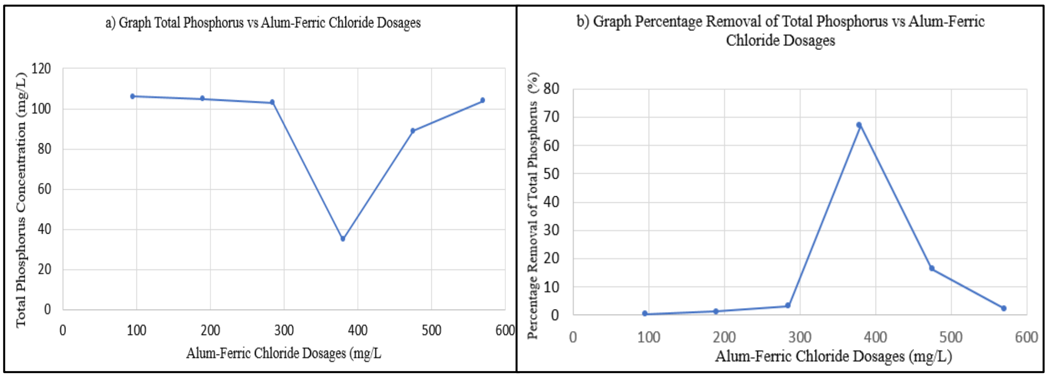


Figure 42: Effluent (a) Total Phosphorus Concentration vs Alum-Ferric Chloride Dosages and (b) Percentage Removal of Total Phosphorus vs Alum-Ferric Chloride Dosages

From Figure 42, the highest total phosphorus removal, 67.1%, occurs at alum-ferric chloride dosages of 380 mg/L, whereas the lowest removal, 0.4%, is observed at alum-ferric chloride dosages of 95 mg/L with average concentration of 106.0 mg/L. These results indicate that alum-ferric chloride dosages of 380 mg/L was efficient in removing total phosphorus. However, the concentration does not meet the standard B discharge limit of 10 mg/L for industrial wastewater. Therefore, further treatment using biological treatment system is required to reduce the Total Phosphorus concentration. Table 48 shows the average effluent total phosphorus concentration throughout the study period for each pH and the percentage total phosphorus removals.

Table 48: Average Total Phosphorus removal

Alum-Ferric Dosages	Percentage total phosphorus removal (%)
95	0.4
190	1.3
285	3.2
380	67.1
475	16.4
570	2.3

4.2.7 Results of Experiment 7: Variation of pH and Lime Dosage in Electronic Wastewater, with Fixed Alum Dosage of 100 mg/L

4.2.7.1 Effluent COD Results throughout the Study

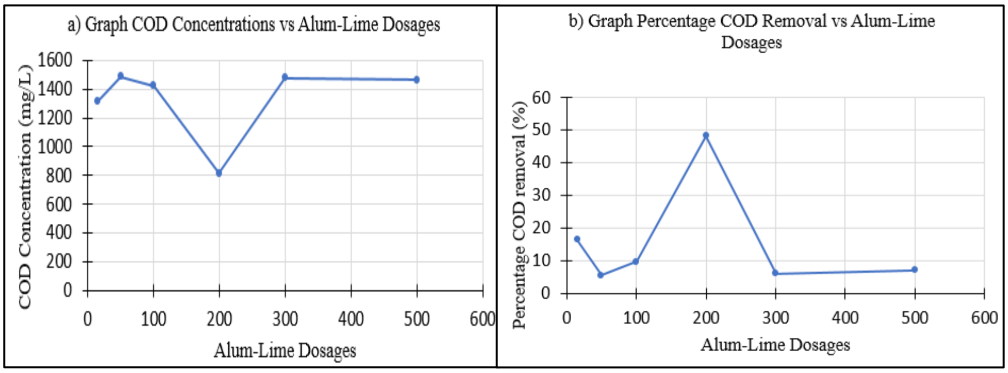


Figure 43: Result of (a) COD concentration vs Alum-Lime Dosages, and (b) COD removal vs Alum-Lime Dosages

Based on the line graph for COD in Figure 43, it can be observed that the COD concentration decreases at alum-lime dosages of 200 mg/L, with COD concentrations of 813 mg/L. However, the COD concentration does not vary very much from alum-lime dosages of 100 mg/L , 300 mg/L, and 500 mg/L with COD concentration of 1421 mg/L, 1478 mg/L, and 1463 mg/L, respectively. The lowest COD removal, at 5.5%, is observed at alum-lime dosages of 50 mg/L, while the highest removal of COD, at 48.3%, occurs at alum-lime dosage of 200 mg/L. Table 49 presents the average COD removal throughout the study period for each pH. Nevertheless, all effluent COD levels still exceed the standard B discharge limit of 200 mg/L.

Table 49: Averaged COD Removals

Alum-Lime Dosages	Percentage COD removal (%)
15	16.5
50	5.5
100	9.7
200	48.3
300	6.1

4.2.7.2 Effluent Turbidity Results throughout the Study

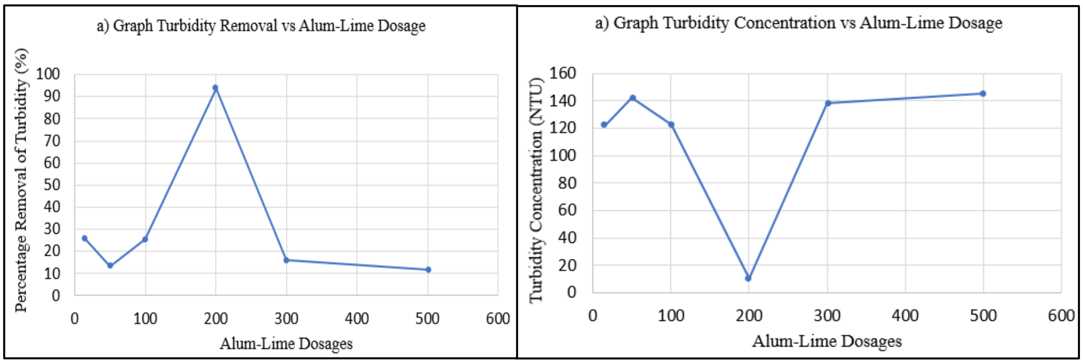


Figure 44: Result of (a) Turbidity value vs Alum-Lime Dosages and (b) Percentage Removal of Turbidity vs Alum-Lime Dosages

From Figure 44, it can be observed that the turbidity value does not vary very much except for alum-lime dosage of 200 mg/L. The highest turbidity removal was 93.8% which at alum-lime dosage of 200 mg/L, while the lowest turbidity removal was 11.6% at alum-lime dosage of 500 mg/L. Table 50 shows the average effluent turbidity value throughout the study period for each alum-lime dosage and the average turbidity removals.

Table 50: Averaged Turbidity Removals

Alum-Lime Dosages	Average turbidity removal (%)
15	25.6
50	13.4
100	25.3
200	93.8
300	15.9
500	11.6

Effluent Total Suspended Solid (TSS) Results throughout the Study

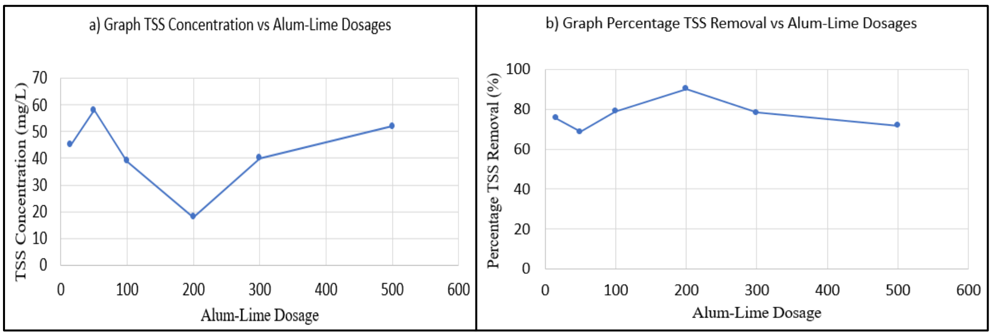


Figure 45: Effluent (a) Total Suspended Solid (TSS) vs Alum-Lime Dosages and (b) Percentage TSS Removal vs Alum Lime Dosages

From Figure 45, a decrease in TSS concentration is observed from alum-lime dosages of 100 mg/L to 200 mg/L with average TSS concentration of 39 mg/L and 18 mg/L respectively. The highest TSS removal was, 90.3% occurs at 200 mg/L of alum-lime dosage with average concentration of 18 mg/L whereas the lowest removal, 68.6% is observed at 50 mg/L of alum-lime dosage with average concentration of 58 mg/L. These results indicate that 200 mg/L of alum-lime dosage is highly efficient in removing TSS, meeting the standard A discharge limit for industrial wastewater which is 120 mg/L. Table 51 presents the average TSS removal throughout the study period for each pH.

Table 51: Average TSS removal

Alum-Lime Dosages	Average Percentage TSS removal (%)
15	75.7
50	68.6
100	78.9
200	90.3
300	78.4
500	71.9

4.2.7.3 Effluent Nitrate-Nitrogen Results throughout the Study

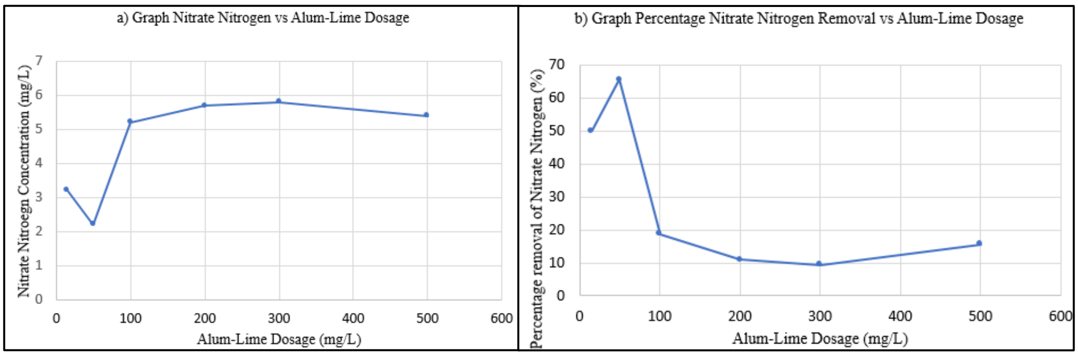


Figure 46: (a) Effluent Nitrate Nitrogen vs Alum-Lime Dosages and (b) Percentage removal of nitrate nitrogen vs Alum-Lime Dosages

From Figure 46, it can be observed a nitrate nitrogen concentration for alum-lime dosage of 15 mg/L, 50 mg/L, 100 mg/L, 200 mg/L, 300 mg/L, and 500 mg/L were not varied very much with the addition of alum-lime coagulant, with average nitrate nitrogen concentration of 3.2 mg/L, 2.2 mg/L, 5.2 mg/L, and 5.7 mg/L, 5.8 mg/L, and 5.4 mg/L respectively. However, there was slightly decrease at 50 mg/L of alum-lime dosage, with average Nitrate-Nitrogen concentration of 2.2 mg/L. Each alum-lime dosage was meeting standard A discharge limit of 20mg/L. Table 52 shows the average nitrate removal throughout the study period for each alum-lime dosage.

Table 52: Average Nitrate Removals

Alum-Lime Dosages	Average percentage of nitrate removal (%)
15	50
50	65.6
100	18.8
200	10.9
300	9.4
500	15.6

4.2.7.4 Effluent Ammonia-Nitrogen Results throughout the Study

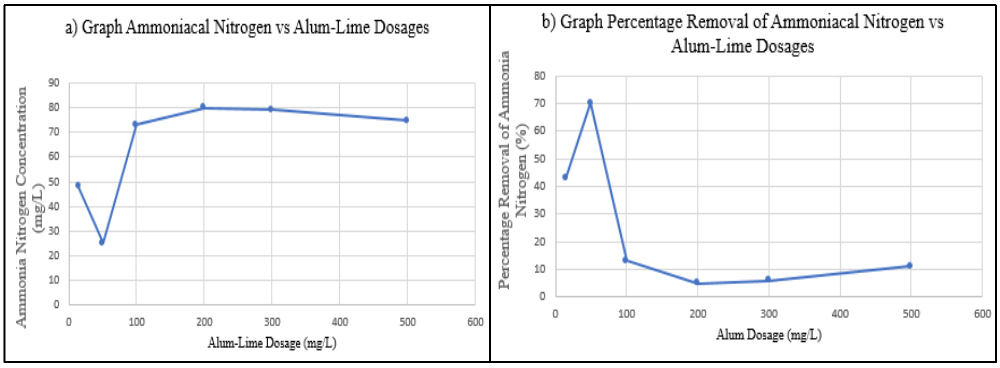


Figure 47: Effluent (a) Ammonia Nitrogen vs Alum-Lime Dosages and (b) Percentage Removal of Ammonia Nitrogen vs Alum-Lime Dosages

From Figure 47, the ammonia nitrogen concentration was decreasing at alum-lime dosage of 50 mg/L with average ammonia nitrogen concentration of 25 mg/L. It was also the highest removal of ammonia nitrogen was occurred at alum-lime dosage of 25 mg/L, which is at 70.2% ammonia removal. Whereas the lowest removal, 50.9%, is observed at pH 2. These results indicate that alum-lime dosage of 50 mg/L are highly efficient in removing ammonia but it is not within standard B discharge limit. Table 53 presents the average effluent ammonia concentrations throughout the study period for each alum-lime dosage and the corresponding average ammonia removals.

Table 53: Average Effluent Ammonia/Ammonia Removal

Alum-Lime Dosages	Average ammonia nitrogen concentration (mg/L)	Percentage ammonia removal (%)
15	48	42.9
50	25	70.2
100	73	13.1
200	79.8	5
300	79	6
500	74.6	11.2

4.2.7.5 Effluent Total Phosphorus Results throughout the Study

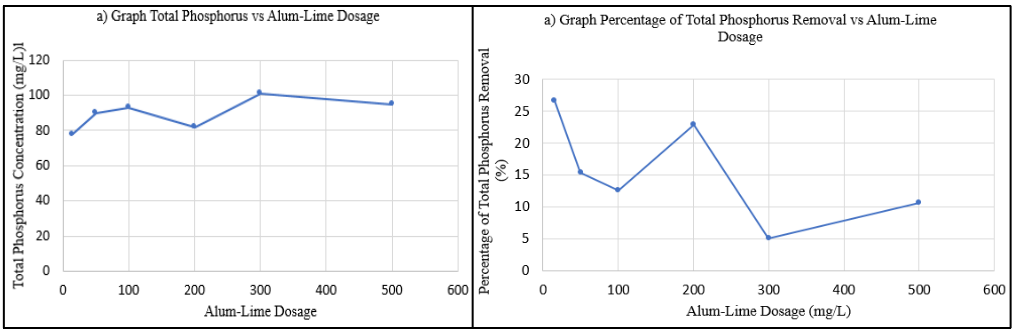


Figure 48: Effluent (a) Total Phosphorus Concentration vs Alum-Lime Dosages and (b) Percentage Removal of Total Phosphorus vs Alum-Lime Dosages

From Figure 48, it can be observed that Total Phosphorus Concentration does not vary very much for each alum-lime dosage. The highest total phosphorus removal, 26.7%, occurs at alum-lime dosage of 15 mg/L, whereas the lowest removal, 5.1%, was observed at alum-lime dosage of 300 mg/L with average concentration of 101 mg/L. All of the alum-lime dosage does not meet the standard B discharge limit of 10 mg/L for industrial wastewater. Therefore, further treatment using biological treatment system is required to reduce the Total Phosphorus concentration. Table 54 shows the average total phosphorus removal throughout the study period for each alum-lime dosage.

Table 54: Average Effluent Total Phosphorus Concentration/Total Phosphorus removal

Alum-Lime Dosages	Percentage total phosphorus removal (%)
15	26.7
50	15.4
100	12.6
200	22.9
300	5.1
500	10.7

4.2.8 Results of Experiment 8: Optimum pH and Optimum Dosage for Alum and Alum-Lime Coagulant

The section analysed optimum pH and optimum dosage for two coagulant which is Aluminium Sulfate and Alum-Lime Coagulant

4.2.8.1 Fixed the dosages of Alum Dosage to 500 mg/L and pH 10 for Electronic Wastewater

Table 55 shows the average effluent organic and nutrient throughout the study period and the percentage organic and nutrient removal by using Alum as coagulant.

Table 55: Average Total Concentration and Percentage removal for Optimum pH and dosage of Alum

Parameter	Unit	Average total concentration	Percentage removal (%)
COD	mg/L	269	82.9
Turbidity	NTU	1.41	97.9
TSS	mg/L	27	85.4
Nitrate Nitrogen	mg/L	0.8	87.5
Ammonia Nitrogen	mg/L	12	85.7
Total Phosphorus	mg/L	46	56.7

According to Table 55, utilizing a fixed alum dosage of 500 mg/L and maintaining a pH of 10 is effective in achieving high removal efficiencies for various parameters in electronic wastewater. However, challenges persist in meeting regulatory discharge limits for COD and total phosphorus. Further optimization of treatment processes or additional treatment steps may be required to ensure full compliance with discharge standards.

4.2.8.2 Calculation of Alum for Industry

Q = 2.9 m^3/hr = 0.0483 m^3/min = 0.00027 m^3/s

Using one flash mixers, we determined the discharge for one flash mixer as (0.0483m^3/min) / 1 = 0.0483 m^3/min.

Use t = 1 min (60 sec),
Volume of flash mixer (V) = 0.0483 × 1 min= 0.0483m^3

Depth of the tank (d) = 3 m
A = V / d = 0.0483 m^3 / 3 m = 0.0161 m^2
The circular section of the tank was used, and the diameter was obtained using the following equation:

$$D = \frac{\sqrt{4}\text{x }(0.0161\text{m}3)}{\pi} = 0.1432\text{, say } 0.2\text{ m}$$

At T = 20 °C, dynamic viscosity (µ = 1.0087 ×10-3 Pa. s) was determined in accordance with previously described methods [13]: For rapid mixing, G is >300/s or more

G = 1,000/s is proposed to be used in power calculation (McGee, 1991)
V = 0.0483 m^3
Power = P = G2 µV (3) (Metcalf & Eddy, 2014)
where G is the mean velocity gradient (/s), P is the power dissipated (watt), µ is the dynamic viscosity (Pa/s), and V is the volume of the tank (m3).
P = (1,000/s) × (1.0087 × 10-3 Pa/s) × (0.0483 m^3)
P = 0.04872 Watt ≈ 0.00004872 kW
To determine the amount of the coagulant (e.g., alum) required per day (kg/day), we used the optimum dosage of alum at 500 mg/L (normally optimum dosage determined by Jar test), and we supposed that the density of alum was 600 kg/m3.
Q = 0.00027 m3 /s × 3600 × 24 = 23.33 m^3 /day
Percentage of alum concentration: 10%
Optimum dosages through jar test: 500 mg/L

$$\text{Amount of alum} = \frac{500\,mg}{L}\ x\ \frac{1000\,L}{1}\ x\ \frac{1\,kg}{1000\,mg}\ x\ \frac{23.33\,m3}{day}$$

=11,665.00 kg/day x 0.1% (10% of alum) =1,166.5 kg/day

= 34,995 kg/month

Density = mass/volume

Volume of alum = mass / density
=1,166.50 kg/day / 600 kg/m3 = 1.944 m3 /day
= 58.3 m^3 /month

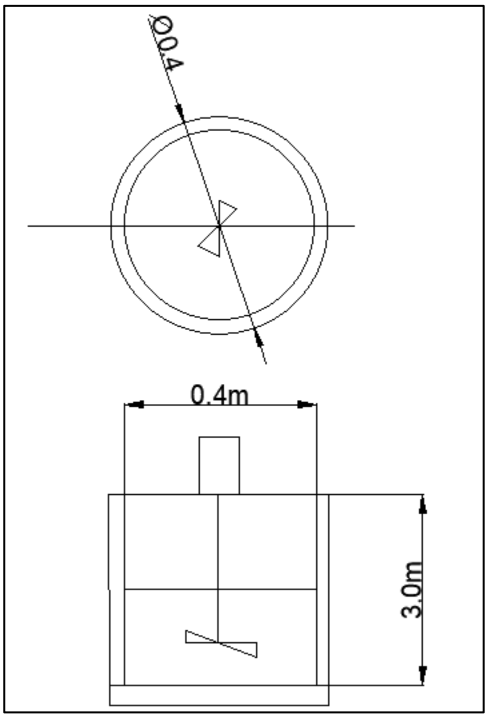


Figure 49: Details of Coagulation tanks

4.2.8.3 Fixed the dosages of Alum Dosage to 500 mg/L, Lime Dosage to 200 mg/L and pH 10 for Electronic Wastewater

Table 56 shows the average effluent organic and nutrient throughout the study period and the percentage organic and nutrient removal by using Alum-Lime as coagulant.

Table 56: Average Total Concentration and Percentage removal for Optimum pH and dosage of Alum-Lime Coagulant

Parameter	Unit	Average total concentration	Percentage removal (%)
COD	mg/L	327	79.2
Turbidity	NTU	1.05	99.4
TSS	mg/L	18	90.3
Nitrate Nitrogen	mg/L	0.3	95.3
Ammonia Nitrogen	mg/L	19	77.4
Total Phosphorus	mg/L	52	51.1

According to Table 56, employing a constant alum dosage of 500 mg/L and lime dosage of 200 mg/L, while maintaining a pH of 10, proves to be effective in achieving high removal efficiencies for various parameters in electronic wastewater. Nevertheless, challenges persist in meeting regulatory discharge limits for COD and total phosphorus. Therefore, further optimization of treatment processes or the inclusion of additional treatment steps may be necessary to ensure full compliance with discharge standards.

4.2.8.4 Calculation of Lime for Industry

Q = 2.9 m^3/hr = 0.0483 m^3/min = 0.00027 m3/s

Using one flash mixers, we determined the discharge for one flash mixer as (0.0483m^3/min) / 1 = 0.0483 m^3/min.

Use t = 1 min (60 sec),
Volume of flash mixer (V) = 0.0483 × 1 min= 0.0483m^3

Depth of the tank (d) = 3 m
A = V / d = 0.0483 m^3 / 3 m = 0.0161 m^2
The circular section of the tank was used, and the diameter was obtained using the following equation:

$$D = \frac{\sqrt{4}\text{x }(0.0161\text{m3})}{\pi} = 0.1432\text{, say 0.2 m}$$

At T = 20 °C, dynamic viscosity (μ = 1.0087 ×10-3 Pa. s) was determined in accordance with previously described methods [13]: For rapid mixing, G is >300/s or more

G = 1,000/s is proposed to be used in power calculation (McGee, 1991)
V = 0.0483 m^3
Power = P = G2 μV (3) (Metcalf & Eddy, 2014)
where G is the mean velocity gradient (/s), P is the power dissipated (watt), μ is the dynamic viscosity (Pa/s), and V is the volume of the tank (m3).
P = (1,000/s) × (1.0087 × 10-3 Pa/s) × (0.0483 m^3)
P = 0.04872 Watt ≈ 0.00004872 kW
To determine the amount of the coagulant (e.g., alum) required per day (kg/day), we used the optimum dosage of alum at 500 mg/L (normally optimum dosage determined by Jar test), and we supposed that the density of alum was 600 kg/m3.
Q = 0.00027 m3 /s × 3600 × 24 = 23.33 m^3 /day
Percentage of alum concentration: 10%
Optimum dosages of lime through jar test: 200 mg/L

$$\text{Amount of alum} = \frac{200\ mg}{L}\ x\ \frac{1000\ L}{1}\ x\ \frac{1\ kg}{1000\ mg}\ x\ \frac{23.33\ m3}{day}$$

= 4,666 kg/day x 0.1% (10% of lime) = 466.6 kg/day

= 13,998 kg/month

Density = mass/volume

Volume of alum = mass / density
= 466.6 kg/day / 2211 kg/m3 = 0.21 m3 /day
= 6.33 m^3 /month

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

The optimum pH and dosage of precipitant were determined through a series of jar test experiments. Coagulant dose and pH play crucial roles in the industrial wastewater treatment process. The performance of Aluminium Sulphate, Ferric Chloride, Alum-Ferric coagulant, and Alum-lime coagulant was compared under these optimal conditions. Alum coagulant showed better results compared to the other coagulants. The results indicate that under the optimum pH of 10 and optimum dosage of 500 mg/L, Aluminium Sulphate removed 82.9% of COD, 97.9% of turbidity, 85.4% of TSS, 87.5% of Nitrate Nitrogen, 85.7% of Ammonia Nitrogen, and 56.7% of Total Phosphorus. For Alum-Lime coagulant, the optimum conditions were at pH 10 and lime dosage of 200 mg/L. Alum-Lime coagulant removed 79.2% of COD, 99.4% of turbidity, 90.3% of TSS, 95.3% of Nitrate Nitrogen, 77.4% of Ammonia Nitrogen, and 51.1% of Total Phosphorus. However, phosphorus and COD levels did not meet the Standard B discharge limit. Therefore, it is suggested to combine an extended aeration activated sludge system with a chemical treatment system to remove COD and phosphorus, as the COD/BOD ratio is above 0.2 but below 0.5, indicating that the wastewater is biodegradable. Extended aeration systems typically have lower energy requirements compared to other activated sludge processes due to their longer aeration times and lower biomass concentrations, resulting in lower operational costs, making them an attractive option for certain applications. It is recommended that industries use 15.1 kg of Alum to treat 35m^3 of electronic wastewater in an equalization tank with a flow rate of 2.9 m^3/hr.

5.2 Recommendation

1. Future studies should look at the organic and nutrient removal by combining chemical treatment system and biological treatment system to ensure the effluent discharge can meet the standard effluent discharge limit.
2. Other type of coagulant such as natural coagulant can be investigated to remove organic and nutrient from industrial wastewater.
3. Optimal dosage and optimal pH through jar tests or pilot-scale studies using different rate of revolutions per minute (rpm), different flocculation, and sedimentation time can be studies to remove organic and nutrient from industrial wastewater.

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APPENDICES

Appendix 1: Average COD Removal for Experiment 1

pH	Average COD concentration (mg/L)
2	998
4	1006
6	854
8	660
10	493
12	690

Appendix 2: Average Turbidity Concentration for Experiment 1

pH	Average turbidity removal (mg/L)
2	137
4	143
6	156
8	14.2
10	1.41
12	6.4

Appendix 3: Average TSS Concentration for Experiment 1

pH	Average TSS removal (mg/L)
2	35
4	39
6	58
8	15
10	5
12	10

Appendix 4: Average Nitrate Concentration for Experiment 1

pH	Average nitrate concentration (mg/L)
2	5.5
4	3.1
6	2.2
8	2.3
10	1.1
12	4.3

Appendix 5: Average Ammonia Concentration for Experiment 1

pH	Average ammonia removal (mg/L)
2	64.8
4	38
6	34
8	31.4
10	10.2
12	19.6

Appendix 6: Average Total Phosphorus Concentration for Experiment 1

pH	Average total phosphorus concentration (mg/L)
2	99
4	67.6
6	83.6
8	70
10	43
12	86

Appendix 7: Average COD Removal for Experiment 2

Alum Dosages (mg/L)	Average COD Concentration (mg/L)
15	1158
50	1467
100	1118
200	1077
300	1102
500	1119

Appendix 8: Average Turbidity Concentration vs for Experiment 2

Alum Dosage (mg/L)	Average turbidity removal (NTU)
15	145
50	140
100	132
200	15
300	5.16
500	2.13

Appendix 9: Average TSS Concentration vs for Experiment 2

Alum Dosage (mg/L)	Average TSS removal (mg/L)
15	52
50	43
100	32
200	14
300	12
500	7

Appendix 10: Average Nitrate Nitrogen Concentration for Experiment 2

Alum Dosage (mg/L)	Average nitrate removal (mg/L)
15	3.8
50	1.8
100	2.1
200	0.4
300	4.2
500	3.6

Appendix 11: Average Ammonia Nitrogen Concentration for Experiment 2

Alum Dosage (mg/L)	Average ammonia nitrogen concentration (mg/L)
15	31.8
50	23.6
100	27.6
200	22
300	53.4
500	41

Appendix 12: Average Total Phosphorus Concentration for Experiment 2

Alum Dosage (mg/L)	Average total phosphorus concentration (mg/L)
15	106.2
50	80.4
100	95.2
200	61
300	3
500	99.6

Appendix 13: Average COD Concentration for Experiment 3

pH	Average COD Concentration (mg/L)
2	1154
4	1206
6	1085
8	617
10	307
12	1314

Appendix 14: Average COD Concentration for Experiment 3

pH	Average turbidity removal (NTU)
2	101
4	94
6	89
8	2.3
10	0.8
12	1.9

Appendix 15: Average TSS Concentration for Experiment 3

pH	Average TSS Concentration (mg/L)
2	55
4	48
6	36
8	9
10	2
12	4

Appendix 16: Average Nitrate Nitrogen Concentration for Experiment 3

pH	Average nitrate nitrogen concentration (mg/L)
2	3.3
4	2.5
6	1.7
8	1.3
10	0.3
12	1.8

Appendix 17: Average Ammonia Nitrogen Concentration for Experiment 3

pH	Average ammonia nitrogen concentration (mg/L)
2	41.2
4	29.8
6	22.8
8	19.8
10	10
12	25

Appendix 18: Average Total Phosphorus Concentration for Experiment 3

pH	Average total phosphorus concentration (mg/L)
2	98.4
4	56
6	55
8	52
10	18
12	80

Appendix 19: Average COD Concentration for Experiment 4

Ferric Chloride Dosages	Average COD Concentration (mg/L)
45	1223
90	1196
135	1374
180	1347
225	1428
270	1430

Appendix 20: Average Turbidity Concentration for Experiment 4

Ferric Chloride Dosages	Average turbidity removal (NTU)
45	89
90	72
135	69
180	25
225	38
270	39

Appendix 21: Average TSS Concentration for Experiment 4

Ferric Chloride Dosages	Average TSS Concentration (mg/L)
45	47
90	35
135	29
180	19
225	21
270	28

Appendix 22: Average Nitrate Concentration for Experiment 4

Ferric Chloride Dosages	Average nitrate nitrogen concentration (mg/L)
45	5.1
90	4.3
135	1.9
180	2
225	0.4
270	3.2

Appendix 23: Average Ammonia Concentration for Experiment 4

Ferric Chloride Dosages	Average ammonia nitrogen concentration (mg/L)
45	42.2
90	35.4
135	16.2
180	15
225	17
270	55.2

Appendix 24: Average Total Phosphorus Concentration for Experiment 4

Ferric Chloride Dosages	Average total phosphorus concentration (mg/L)
45	99.3
90	94.6
135	92.4
180	63
225	67
270	98

Appendix 25: Average COD Concentration for Experiment 5

pH	Average COD Concentration (mg/L)
2	1278
4	1197
6	1156
8	734
10	498
12	1192

Appendix 26: Average Turbidity Concentration for Experiment 5

pH	Average turbidity (NTU)
2	129
4	132
6	28
8	26
10	1.42
12	3.9

Appendix 27: Average TSS Concentration for Experiment 5

pH	Average TSS Concentration (mg/L)
2	39.0
4	41.0
6	11.0
8	9.3
10	2.8
12	7.4

Appendix 28: Average nitrate nitrogen Concentration for Experiment 5

pH	Average nitrate nitrogen concentration (mg/L)
2	2.8
4	2.2
6	1.7
8	1.5
10	0.6
12	2.5

Appendix 29: Average ammonia nitrogen Concentration for Experiment 5

pH	Average ammonia nitrogen concentration (mg/L)
2	41.2
4	29.8
6	22.8
8	19.8
10	12
12	25

Appendix 30: Average total phosphorus concentration for Experiment 5

pH	Average total phosphorus concentration (mg/L)
2	105.7
4	89.4
6	81
8	78
10	35

Appendix 31: Average COD Concentration for Experiment 6

Alum-Ferric Dosages	Average COD Concentration (mg/L)
95	1454
190	1387
285	1413
380	820
475	1211
570	1394

Appendix 32: Average Turbidity Concentration for Experiment 6

Alum-Ferric Dosages	Average turbidity removal (NTU)
95	8.9
190	5.6
285	1.6
380	1.2
475	0.9
570	1.1

Appendix 33: Average TSS Concentration for Experiment 6

Alum-Ferric Dosages	Average TSS Concentration (mg/L)
95	23
190	15
285	10
380	8.3
475	2.9
570	7.9

Appendix 34: Average Nitrate Nitrogen Concentration for Experiment 6

Alum-Ferric Dosages	Average nitrate nitrogen concentration (mg/L)
95	6.2
190	5.9
285	6.3
380	3.6
475	4.3
570	5.8

Appendix 35: Average Ammonia Nitrogen Concentration for Experiment 6

Alum-Ferric Dosages	Average ammonia nitrogen concentration (mg/L)
95	69.8
190	50.2
285	65.4
380	25.8
475	48.4
570	57.8

Appendix 36: Average Total Phosphorus Concentration for Experiment 6

Alum-Ferric Dosages	Average total phosphorus concentration (mg/L)
95	106
190	105
285	103
380	35
475	89
570	104

Appendix 37: Average COD Concentration for Experiment 7

Alum-Lime Dosages	Average COD Concentration (mg/L)
15	1314
50	1487
100	1421
200	813
300	1478

Appendix 38: Average Turbidity value for Experiment 7

Alum-Lime Dosages	Average turbidity removal (NTU)
15	122
50	142
100	122.5
200	10.2
300	138
500	145

Appendix 39: Average TSS concentration for Experiment 7

Alum-Lime Dosages	Average TSS Concentration (mg/L)
15	45
50	58
100	39
200	18
300	40
500	52

Appendix 40: Average Nitrate concentration for Experiment 7

Alum-Lime Dosages	Average nitrate nitrogen concentration (mg/L)
15	3.2
50	2.2
100	5.2
200	5.7
300	5.8
500	5.4

Appendix 41: Average Ammonia concentration for Experiment 7

Alum-Lime Dosages	Average ammonia nitrogen concentration (mg/L)
15	48
50	25
100	73
200	79.8
300	79
500	74.6

Appendix 42: Average Total Phosphorus concentration for Experiment 7

Alum-Lime Dosages	Average total phosphorus concentration (mg/L)
15	78
50	90
100	93
200	82
300	101
500	95

Appendix 43: Jar Test using different coagulant