# CHARACTERIZATION AND PERFORMANCE EVALUATION OF LIGNIN-BASED BIOFLOCCULANTS FOR ORGANIC MICROPOLLUTANTS IN ADSORPTIVE COAGULATION-FLOCCULATION PROCESS

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# ABSTRACT

The emergence of organic micropollutants in surface water, sewage influent, and sewage effluent has raised public concern. It might lead to the dispersion of antibiotic resistance, which has a massive impact on human health and economic consequences globally. Besides, the increasing demand for environmentally friendly technology in the wastewater treatment process has recently gained considerable attention, especially, towards the application of natural-based coagulants/flocculants. The enormous amount of oil palm empty fruit bunches (OPEFB) produced throughout the years gives the potential for this biomass to be used as a source in the synthesis of lignin-based flocculant. Thus, this study focused on the extraction of lignin from OPEFB using ionic liquid dissolution-alkaline treatment technique and modification of extracted lignin into quaternized lignin (QL). The extracted lignin was characterized using Fourier transform infrared spectroscopy, Gel permeation chromatography and thermogravimetric analysis. The lignin-based flocculant was synthesized using quaternization method with 3-chloro-2-hydroxylpropyl trimethylammonium chloride (CHPTAC). The lignin-based flocculant was characterized using Fourier transform infrared spectroscopy, hydrogen nuclear magnetic resonance spectroscopy and CHNS elemental analysis. The performance of QL in removing turbidity of the kaolin suspension solution was evaluated using a jar test method at various experimental conditions such as the molar ratio of CHPTAC to phenylpropanoid unit of lignin, flocculant dosages, pH values, kaolin concentrations, slow mixing rates and sedimentation times. It was found that the QL10 achieved the highest turbidity removal efficiency ($\mathcal{E}_t$) 99.46 ± 0.28 (%) using 5 mg $L^{-1}$ of flocculant dosage, pH 7, 1000 mg $L^{-1}$ of kaolin concentration and required 20 min of sedimentation time at all the slow mixing rates tested. Response surface methodology was utilized to find the optimum combination of flocculant dosage, pH of kaolin suspension and kaolin concentration concerning the highest $\mathcal{E}_t$ and the lowest sludge volume index (SVI). Results revealed that the optimal conditions were 10 mg $L^{-1}$ dosage, pH 7 and 1420.45 mg $L^{-1}$ kaolin concentration to obtain 99.09 % and 5.42 mL $g^{-1}$ of $\mathcal{E}_t$ and SVI respectively. The applicability of lignin-based flocculant in the adsorptive coagulation-flocculation process was evaluated using a jar test to remove oxytetracycline (OTC) as micropollutant from simulated wastewater. Natural zeolite was added during the adsorptive coagulation-flocculation process to improve the removal of OTC. It was found that the removal efficiency of OTC increased up to 85.04 % at pH 9, OTC concentration of 100 μM and 2000 mg $L^{-1}$ of zeolite dosage. The kinetic of OTC removal was studied at various zeolite dosages and obeyed a pseudo-second order model. The dewatering study showed that the coagulation-flocculation process with 10 mg $L^{-1}$ QL10 resulted in 0.86 x $10^{12}$ m $kg^{-1}$ of specific resistance to filtration and 92 s of time to filter. In conclusion, lignin-based flocculant was successfully synthesized in this study and OPEFB lignin has shown an ability to be turned into a flocculant for wastewater treatment as well as overcoming the problems of oil palm plantation waste disposal.

# ABSTRAK


Kemunculan bahan pencemar mikro organik di permukaan air, influen kumbahan, dan aliran keluar kumbahan telah menimbulkan kebimbangan orang ramai. Ia mungkin membawa kepada penyebaran rintangan antibiotik, yang mempunyai kesan besar terhadap kesihatan manusia dan ekonomi di seluruh dunia. Selain itu, permintaan yang semakin meningkat untuk teknologi mesra alam dalam proses rawatan air sisa baru-baru ini mendapat perhatian yang ketara, terutamanya, terhadap penggunaan pengental/pembuku berasaskan bahan semulajadi. Sejumlah besar tandan buah kosong kelapa sawit (OPEFB) yang dihasilkan sepanjang tahun mempunyai potensi agar biojisim ini digunakan sebagai sumber dalam sintesis pembuku berasaskan lignin. Oleh itu, kajian ini memfokuskan pada pengekstrakan lignin daripada OPEFB menggunakan teknik rawatan pelarutan cecair berion-rawatan alkali dan pengubahsuaian lignin yang diekstrak menjadi lignin berkuaternari (QL). Lignin yang diekstrak telah dicirikan menggunakan spektroskopi inframerah transfomasi Fourier, kromatografi penelapan gel dan analisis termogravimetri. Pembuku berasaskan lignin telah disintesis menggunakan kaedah kuaternisasi dengan 3-kloro-2-hidroksilpropil trimetilammonium klorida (CHPTAC). Pembuku berasaskan lignin telah dicirikan menggunakan spektroskopi inframerah transformasi Fourier, spektroskopi resonans magnet nuklear hidrogen dan analisis unsur CHNS. Prestasi QL dalam menyingkirkan kekeruhan larutan ampaian kaolin dinilai menggunakan kaedah ujian balang pada pelbagai keadaan ujikaji seperti nisbah molar CHPTAC terhadap unit fenilpropanoid lignin, dos pembuku, nilai pH, kepekatan kaolin, kadar pencampuran perlahan dan masa pemendapan. Didapati bahawa QL10 mencapai kecekapan penyingkiran kekeruhan tertinggi ($\mathcal{E}_t$) 99.46 ± 0.28 (%) dengan menggunakan 5 mg $L^{-1}$ dos pembuku, pH 7, 1000 mg $L^{-1}$ kepekatan kaolin dan memerlukan 20 minit masa pemendapan pada semua kadar pencampuran perlahan yang diuji. Kaedah gerakbalas permukaan digunakan untuk mencari kombinasi optimum dos pembuku, pH ampaian kaolin, dan kepekatan kaolin bagi mencapai $\mathcal{E}_t$ tertinggi dan indeks isipadu kumbahan (SVI) terendah. Hasil kajian menunjukkan bahawa keadaan optimum adalah 10 mg $L^{-1}$ dos, pH 7 dan kepekatan kaolin 1420.45 mg $L^{-1}$ untuk masing-masing memperoleh 99.09 % dan 5.42 mL $g^{-1}$ bagi $\mathcal{E}_t$ dan SVI. Kebolehgunaan pembuku berasaskan lignin dalam proses penjerapan pengentalan-pembukuan dinilai menggunakan ujian balang untuk menyingkirkan oksitetrasiklin (OTC) sebagai bahan pencemar mikro daripada air sisa simulasi. Zeolit semula jadi ditambahkan semasa proses penjerapan pengentalan-pembukuan untuk meningkatkan penyingkiran OTC. Didapati bahawa kecekapan penyingkiran OTC meningkat sehingga 85.04 % pada pH 9, kepekatan OTC 100 μM dan 2000 mg $L^{-1}$ dos zeolit. Kinetik penyingkiran OTC dikaji pada pelbagai dos zeolit dan mematuhi model pseudo tertib kedua. Kajian penyahairan menunjukkan bahawa proses pengentalan-pembukuan dengan 10 mg $L^{-1}$ QL10 menghasilkan 0.86 x $10^{12}$ m $kg^{-1}$ rintangan khusus kepada penurasan dan masa 92 s untuk menuras. Kesimpulannya, pembuku berasaskan lignin telah berjaya disintesis dalam kajian ini dan lignin OPEFB telah menunjukkan keupayaan bagi dijadikan pembuku untuk rawatan air sisa serta mengatasi masalah pembuangan sisa ladang kelapa sawit.

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## LIST OF SYMBOLS

| | | |
|---|---|---|
| $\varepsilon_t$ | - | Turbidity removal efficiency (%) |
| $\varepsilon_{OTC}$ | - | Oxytetracycline removal efficiency (%) |
| % wt. | - | Weight percent |
| $Q_t$ | - | Adsorption capacity at time, t (μmol $g^{-1}$) |
| $Q_e$ | - | Adsorption equilibrium at time, t (μmol $g^{-1}$) |
| $k_1$ | - | Pseudo-first-order rate constant ($s^{-1}$) |
| t | - | Time (s) |
| hr | - | hour |
| $k_2$ | - | Pseudo-second order rate constant (μmol $s^{-1}$) |
| $\alpha$ | - | Elovich initial adsorption rate (mg $g^{-1}$ $s^{-1}$) |
| $\beta$ | - | The extent of surface coverage and activation energy for chemisorption (g $mg^{-1}$) |
| $\xi$ | - | Zeta potential (mV) |
| $X_i$ | - | Real value |
| $x_i$ | - | Coded value |
| $Xo$ | - | Value at the centre point |
| $\delta X$ | - | Step change |
| $Y$ | - | Predicted response |
| $b_i$ | - | Linear coefficient |
| $b_{ii}$ | - | Quadratic coefficient |
| $b_{ij}$ | - | Interaction coefficient |
| $R^2$ | - | Coefficient of determination |
| $R^2_{adj}$ | - | Adjusted coefficient of determination |
| $C_o$ | - | Initial concentration of OTC at t = 0 (μmol $L^{-1}$) |
| $C_t$ | - | Final concentration of OTC at time t (μmol $L^{-1}$) |
| $V$ | - | Volume (L) |
| $m$ | - | Mass of kaolin (mg) |
| $b$ | - | A slope determined from the plot of t/vol vs vol (s $m^{-6}$) |
| $P$ | - | Pressure of filtration (N $m^{-2}$) |
| $A$ | - | Area of filtration ($m^2$) |

| | | |
|---|---|---|
| $\mu$ | - | Filtrate viscosity (Ns $m^{-2}$) |
| w | - | Dry mass of cake solids deposited per volume of filtrate (kg $m^{-3}$) |
| $N$ | - | Normality |
| $A$ | - | Absorbance at 205 nm |
| $W$ | - | Oven-dry mass (mg or g) |
| $df$ | - | Dilution factor |
| $l$ | - | Cell path length (1 cm) |
| $a$ | - | Absorptivity equal to 110 L/g.cm |
| $W_o$ | - | Initial mass before oven-dry (g) |
| $W_1$ | - | Weight of ash (g) |
| $W$ | - | Weight of ambient-dry OPEFB (g) |
| $M_w$ | - | Weight-average molecular weight (g $mol^{-1}$) |
| $M_n$ | - | Number-average molecular weight (g $mol^{-1}$) |
| $DS$ | - | Substitution degree of sulfur |
| $\%N$ | - | Amount of nitrogen content detected by elemental analyzer (% wt.) |
| $\%S$ | - | Amount of sulfur content detected by elemental analyzer (%) |
| $T_i$ | - | Initial turbidity (NTU) |
| $T_f$ | - | Final turbidity (NTU) |
| $D_1$ | - | Initial DO of sample (mg $L^{-1}$) |
| $D_2$ | - | Final DO of sample (mg $L^{-1}$) |
| $B_1$ | - | Initial DO of seed (mg $L^{-1}$) |
| $B_2$ | - | Final DO of seed (mg $L^{-1}$) |
| $w_{RF}$ | - | Weight of residue and filter paper (g) |
| $w_F$ | - | Weight of filter paper (g) |

## LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| [bmim][Cl] | - | 1-butyl-3-methyl-imidazolium chloride |
| $^{1}$HNMR | - | Hydrogen nuclear magnetic resonance |
| $AlCl_3$ | - | Aluminium chloride |
| $AlK(SO_4)_2.12H_2O$ | - | Aluminium potassium sulphate dodecahydrate |
| ANOVA | - | Analysis of variance |
| ASTM | - | American standard test method |
| BOD | - | Biological oxygen demand |
| CCD | - | Central composite design |
| CHPTAC | - | 3-chloro-2-hydroxypropyltrimethylammonium chloride |
| $CO_2$ | - | Carbon dioxide |
| COD | - | Chemical oxygen demand |
| DO | - | Dissolved oxygen |
| DOE | - | Design of experiment |
| DLVO | - | Derjaguin–Landau–Verwey–Overbeek |
| DS | - | Degree of substitution |
| DTG | - | Derivative weight |
| EDCs | - | Endocrine-disrupting compounds |
| EE2 | - | 17α-ethinylestradiol |
| EFB | - | Empty fruit bunches |
| EPTMAC | - | 2, 3-epoxypropyl trimethylammonium chloride |
| F-test | - | Fisher test |
| FTIR | - | Fourier transform infrared |
| GDP | - | Gross domestic product |
| GPC | - | Gel permeation chromatography |
| $H_2SO_4$ | - | Sulphuric acid |
| $HNO_3$ | - | Nitric acid |
| HPLC | - | High performance liquid chromatography |
| IL | - | Ionic liquid |
| KOH | - | Potassium hydroxide |
| LAS | - | Linear alkylbenzene sulfonates |
| $NaClO_2$ | - | Sodium chlorite |

| | | |
|---|---|---|
| NaOH | - | Sodium hydroxide |
| NOM | - | Natural organic matter |
| NTU | - | Nephelometric turbidity units |
| OPEFB | - | Oil palm empty fruit bunch |
| OPB | - | Oil palm biomass |
| OTC | - | Oxytetracycline |
| PACl | - | Polyaluminium chloride |
| PAFCl | - | Polyaluminium ferric chloride |
| PAM | - | Polyacrylamide |
| PAS | - | Polyaluminium sulphate |
| PCB | - | Polychlorinated biphenyls |
| PDADMAC | - | Polydiallyldimethyl ammonium chloride |
| PFA | - | Polyfluorinated alkylated |
| PFC | - | polyferric chloride |
| PFS | - | Polyferrous sulphate |
| PFOA | - | Perfluorooctanoic acid |
| PFOS | - | Perfluorooctane sulfonate |
| PPCPs | - | Pharmaceutical and personal care products |
| p-value | - | Probability value |
| QL | - | Quaternized lignin |
| RSM | - | Response surface methodology |
| SRF | - | Specific resistance of filtration |
| STPs | - | Sewage treatment plants |
| SVI | - | Sludge volume index |
| TGA | - | Thermogravimetric analysis |
| THF | - | Tetrahydrofuran |
| TMSP | - | Sodium trimethylsilyl propionate |
| TSS | - | Total suspended solid |
| TTF | - | Time to filter |
| WWTP | - | Wastewater treatment plant |

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# CHAPTER 1

# INTRODUCTION

## 1.1 Research Background

Lignin is the second most abundant after cellulose and exhibits a great variability of functional groups which makes it an attractive macromonomer for the synthesis of polymers (Monteil-Rivera *et al.*, 2013). It can be extracted from abundantly available lignocellulosic biomass such as oil palm waste which mainly composes of cellulose (30 to 60%), hemicelluloses (17 to 23%), and lignin (18 to 23%) (Mohtar *et al*., 2015; Baruah *et al.*, 2018). Likewise, the amount of oil palm biomass produced from the palm oil industry is also larger than the other crop residues which reported that 80 million tonnes of dry biomass produced in 2010, and expected to rise to 100 million dry tonnes by the year 2020 (Umar *et al*., 2018). Therefore, it is gratifying when many researchers are interested to study the development of lignin from this inexpensive source of lignocellulose that could be further produced as value-added products.

Lignin exhibits a great variability of functional groups including phenolic, aliphatic hydroxyl, methoxyl, carbonyl groups. Due to its nontoxicity, renewability, biodegradability, and abundancy, surging attention has recently focused on developing new applications for lignin beyond its traditional usage for energy such as biofuels (Liakakou *et al*., 2019), antioxidants (Trevisan and Rezende, 2020), adhesives (Chen *et al.*, 2020), and adsorbents (Shi *et al*., 2020). There is also expanding interest in the development of natural coagulant/flocculant by utilizing industrial and agricultural waste lignin as eco-friendly materials. Usually, inorganic coagulants/flocculants such as aluminum sulfate, ferric chloride, and poly aluminum salts are extensively used due to their low cost (Kong *et al.*, 2015). Despite inorganic and synthetic organic polymer flocculants exhibiting high efficiency, some of them, especially alum, polyacrylamide-based flocculants, and chloride ions, may cause secondary pollution due to the residual metal ions and the noxious organic monomers causing severe neurotoxic effects. These conventional coagulants/flocculants also cannot keep up with the increasing demands for organic matter removal (Zahrim *et al.*, 2015). Therefore, continuous studies on developing eco-friendly flocculants through various chemical modifications of natural-based materials like lignin have gained considerable interest recently.

As the population has increased by leaps and bounds, the use of personal care products, drugs, pesticides, and pharmaceuticals has also caused the accumulation of a huge amount of organic micropollutants in sewage water. Effluents of sewage treatment plants have been identified as a major source that introduces organic micropollutants, into the environment (Williams *et al*., 2019). The existence of these components in streams and water sources can cause harm to aquatic life, as well as human health. Most of the existing sewage treatment plants are not specifically designed to remove the organic micropollutants from the waste stream. Thus, it is no surprise that incomplete removal of these compounds has been reported lately (Zhang *et al.*, 2013). Instead of constructing new sewage treatment plants (STPs), it is more economically attractive to develop and improve the coagulation-flocculation process.

Hence, the natural polymers-based coagulant/flocculant should be considered in the treatment plant to remove these organic micropollutants and other components. Besides, the natural-based-coagulant/flocculant is well-known to be non-toxic, abundantly available, and biodegradable and at the same time, it is not disturbing the food resources. The invention of biopolymer-based flocculants, such as tamarind, guar gum, starch, chitin, pectin, alginate, tannin, cellulose, and konjac glucomannan have received attention (Nasrollahzadeh *et al*., 2021). Therefore, lignin from plantation waste, namely oil palm empty fruit bunches, OPEFB, is interesting to be investigated as a flocculant for the removal of organic micropollutants in sewage treatment processes.

## 1.2 Problem Statements

The palm oil industry in Malaysia is expected to grow continuously. However, current technologies (mostly low-cost systems) introduced by the biomass residue management industry may not be adequate to cope with continuous expansion (Onoja *et al*., 2019). Poor management of oil palm biomass can lead to unfavourable environmental consequences. This solid waste from the palm oil industry primarily contains lignocelluloses compounds. Unfortunately, most of them are commonly shredded for in-situ composting or burned as a source of energy (Ahmad *et al.*, 2019). Malaysia has proposed the National Biomass Strategy 2020 by targeting an additional 20 million tonnes of oil palm biomass that could be utilized by the year 2020 for higher value uses, which could significantly contribute to improving Malaysia economy (Ozturk *et al*., 2017). The utilisation of oil palm biomass should therefore be increased in a way to extend sustainability and profit to the relevant industry.

Lignin is the second major component in oil palm biomass (OPB) and has versatile use when derived in a variety of applications. The modification and application of lignin as flocculants have drawn considerable attention due to their high-performance, low-cost, and eco-friendliness (Zhao *et al.*, 2017). Over the past decades, divalent or trivalent salts such as aluminum sulfate, ferrous sulfate, ferric chloride, and synthetic polymer-based flocculants have been used in water purification. However, the utilization of these conventional coagulant/flocculants has raised environmental concerns due to their toxicity, generates excessive chemical sludge, and increases the corrosion rate of metallic utilities (Kurniawan *et al.*, 2020). To avoid the usage of alum, a synthetic organic polymer such as polydiallyldimethylammonium chloride (PDADMAC) (Wang *et al*., 2015) and epichlorohydrin–dimethylamine (Li *et al.*, 2015) have been introduced. Although they have produced good results using a lower dosage, the cost is also increasing due to the rising price of their non-renewable raw materials from petroleum.

Increased attention in recent years has been paid to the developing healthy, environmentally friendly, and cheap technologies natural-based coagulants/flocculants including lignin. Recently, many studies have reported the modification of water-soluble lignin derivatives as coagulants/flocculants. Lignin has been carboxymethylated by treating with monochloroacetic acid (Gan *et al.*, 2013), sulfonification with 3-chloro-2-hydroxypropansulfonic acid sodium (Guo *et al.*, 2018), and cationized by glycidyl trimethylammonium chloride (Wahlström *et al.*, 2017) as attempts to improve its properties as coagulant or flocculant.

Generally, pollutants found in wastewater consist of heavy metals, nitrogen, pathogen, pesticides and suspended solids. In recent years, there are other emerging contaminants in wastewater such endocrine-disruptive compound and pharmaceutical compound. The rise of antibiotics in wastewater due to its' extensive use in veterinary and healthcare medicine has stirred up the awareness among the researchers. The main problem caused by the discharge of antibiotics in the environment is the cultivation of resistant bacteria, which was recognised as one of the top ten threats to global health in 2019 (WHO, 2019). In order to overcome the severe issue, the discharge of antibiotics to the environment should be reduced by implementing effective wastewater treatment technologies.

Adsorptive coagulation-flocculation is one of current technology in wastewater treatment which is the combination of adsorption and coagulation-flocculation. It is an economical method as adsorbents with target pollutants attached on will settle down at sediment tank via coagulation-flocculation. Besides improving the removal of contaminants and turbidity, spent adsorbent can be recovered for disposal (Kumari and Gupta, 2020). The combined process achieved the synergistic effect by reducing the turbidity of wastewater containing antibiotic, settling down the exhausted adsorbent, and, most importantly, removing and degrading antibiotics. Thus, this study has been conducted to investigate the potential of lignin extracted from OPEFB, as a coagulant/flocculant and use in adsorptive coagulation-flocculation process to remove the micropollutant.

## 1.3 Research Objectives

According to the identified problem statements, this research was conducted based on the following objectives:

i. To extract, characterize and synthesized the lignin extracted from OPEFB as lignin-based flocculant

ii. To evaluate the flocculation efficiency of lignin-based flocculant and optimize the performance of the selected lignin-based flocculant

iii. To study the performance of adsorptive coagulation-flocculation and kinetics of the removal micropollutant (antibiotic) from simulated wastewater

## 1.4 Research Scopes

Based on the research objectives, the scopes of the study have been identified and mentioned as bellow:

For the objectives 1:

The extraction of lignin from oil palm empty fruit bunches (OPEFB) was carried out according to the established procedures reported in the literature. First, the extraction was carried out by dissolving the OPEFB in ionic liquid (IL) prior to treatment with an alkaline solution. Second, the extracted lignin was characterized using Fourier Transform Infrared (FTIR) spectroscopy to analyze the functional groups, Gel Permeation Chromatography (GPC) to determine molecular weight, and Thermogravimetric Analysis (TGA) for thermal stability. Third, the lignin-based flocculants were synthesized using extracted lignin via quaternization method with 3-chloro-2-hydroxylpropyl trimethylammonium chloride (CHPTAC) under alkaline condition. Fourt, the lignin-based flocculants were characterized using FTIR Spectroscopy to confirm the quaternization reaction on the lignin, Hydrogen Nuclear Magnetic Resonance ($^1$HNMR) Spectroscopy for structural study and CHNS elemental analysis was used to determine the degree of substitution (DS).

For objectives 2:

The performance of lignin-based flocculants was evaluated using simulated wastewater in the jar test experiment. A few variables like β values (molar ratios of CHPTAC to phenylpropanoid unit of lignin) (1:5, 1:10, 1:15), flocculants dosage of 0.1–50 (mg $L^{-1}$), pH value (3–11), kaolin concentration of 100–2000 mg $L^{-1}$, slow mixing rate of 30–80 (rpm), and sedimentation time between 0–60 (min) were individually studied using one-factor-at-a-time method (OFAT). The evaluation was done based on the turbidity removal efficiency, $\mathcal{E}_t$ (%), and compare with the commercial alum. The research was followed by optimization using Response Surface Methodology (RSM). The optimization step was carried out to study the relationship between the most influence parameters which are flocculant dosage of 1.59–18.41 (mg $L^{-1}$), pH of the kaolin suspension between 1.95–12.05, and kaolin concentration of 159–1840 (mg $L^{-1}$) on the dependent parameter which were turbidity removal efficiency ($\mathcal{E}_t$) and sludge volume index (SVI). The flocculated sludge was further treated to check its dewatering performance based on specific resistance to filtration (SRF) and time to filter (TTF) using a Buchner funnel test.

For objectives 3:

The adsorptive flocculation of antibiotics was evaluated using the jar test method by adding quaternized lignin (QL) as the flocculant and natural zeolite as the adsorbent. Oxytetracycline (OTC) was selected as model antibiotics in the adsorptive flocculation process. The removal performance of OTC was evaluated at various conditions such as initial OTC concentration between 10–250 (μM), pH of the simulated wastewater (3–11), and zeolite concentration range between 150–2000 (mg $L^{-1}$). Meanwhile, the kinetic data was analyzed using the existing kinetic model including pseudo-first order model (PFO), pseudo-second order model (PSO), and Elovich model.

## 1.5 Thesis Outline

This report consists of five chapters. Chapter 1 presents the research background, problem statement, objectives, and scopes of the studies. Chapter 2 reviews the sources of lignin, lignin fractionation and modifications, and applications as flocculants. The second part was discussed on the coagulation-flocculation process, wherein the effect of parameters, mechanisms, and sludge dewatering processes was included. The last part of this chapter is reviewed the adsorptive flocculation and its application in separating antibiotics. Chapter 3 presents the research methodology which comprises materials, experimental procedures, and analytical characterization procedures. The experimental procedures covered the extraction and modification methods, coagulation-flocculation experiments, optimization, kinetics, and dewatering studies. The findings of the study were presented in Chapter 4. In this chapter, the extraction and modification of lignin based-flocculant, the flocculation performance, optimization of selected flocculants, sludge dewatering property, adsorptive flocculation, and kinetic of antibiotic removal were discussed. Chapter 5 presents the conclusions about the findings of the entire research and recommendations for future research are suggested for the aim of improvement.

## 1.6 Summary

The manipulation of oil palm empty fruit bunches (OPEFB) as a feedstock for lignin extraction is significance in terms of environmental and economic value. The modification of lignin into water-soluble coagulant/flocculant can overcome the major drawbacks of conventionally used coagulant/flocculant. Hence, it is useful to understand the performance of lignin-based flocculant derived from OPEFB as replacements for synthetic coagulant/flocculant. The modified lignin was characterized and the efficiency in removing turbidity was compared with commercially used coagulant/flocculant which is an alum. This experiment was also classified as a preliminary step in the selection of significant parameters and the range of parameters for further study in the optimization experiment. The adsorptive coagulation-flocculation was conducted to enhance the removal of organic micropollutant using simulated wastewater. The kinetic data have elucidated the removal of antibiotics using the pseudo-first order model (PFO), pseudo-second order model (PSO), and Elovich model. Finally, the dewatering property of the sludge was also assessed.

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# LIST OF PUBLICATIONS

## Journal with Impact Factor

1. **Md Noor A. M.**, Mohtar S.S., Saman N, Tengku Malim Busu T. N. Z., Shaari N., Yusoff N. A., and Mat H. (2019). Preparation of quaternized lignin derived from oil palm empty fruit bunches and its flocculation properties. Journal of Wood and Chemistry Technology. 39, 399–420. https://doi.org/10.1080/02773813.2019.1636823. (Q1, IF: 2.630)