PREPARATION, CHARACTERISATION AND APPLICATION OF IRON OXIDE-CHITOSAN NANOCOMPOSITES AS FLOCCULANTS FOR PALM OIL MILL EFFLUENT

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UNIVERSITI PENDIDIKAN SULTAN IDRIS

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JULIANA BINTI JUMADI

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ABSTRACT

This research aimed to prepare, characterise and apply four iron oxide-chitosan nanocomposites, namely ferrihydrite-chitosan (FC), goethite-chitosan (GC), hematite-chitosan (HM) and magnetite-chitosan (MC) as flocculants for the pre-treatment of palm oil mill effluent (POME). The nanocomposites were prepared through a co-precipitation method at three (*w/w*) ratios of iron oxide to chitosan. The physicochemical properties of nanocomposites were characterised by using a scanning electron microscope (SEM), X-ray diffraction (XRD) spectrometer, Fourier transform infrared (FTIR) spectrometer, vibrating sample magnetometer (VSM) and thermogravimetric analyser (TGA) before and after flocculation experiments to prove the effectiveness of the nanocomposites. The effects of flocculant dosage, solution pH and settling time on flocculation for the removal of total suspended solids (TSS), turbidity, chemical oxygen demand (COD), oil and grease (O&G) and nutrients (K, Fe, Mn and Cu) were investigated by jar test method. Research findings found that the MC nanocomposite with a ratio of 1:1 (*w/w*) showed the highest percentage of contaminant reduction. The optimal conditions for the reduction of all contaminants were achieved at a flocculant dosage of 1.5 g/L, pH of 5.0 and a settling time of 60 minutes. Under this condition, the reduction of TSS, turbidity, COD and O&G was 86.79%, 82.61%, 74.28% and 62.64%, respectively. After three cycles of flocculation/deflocculation process, MC nanocomposite retained flocculation efficiency and flocculants recovery in the range of 66.7-85.7% and 83-91%, respectively. Combination of charge neutralisation and polymer bridging was the main mechanism of interaction between nanocomposite and POME contaminants. In conclusion, the iron oxide incorporated chitosan has increased the properties and flocculation performance of the nanocomposite as compared to conventional flocculants. In implication, iron oxide-chitosan nanocomposites potentially act as alternative flocculants for pre-treatment of POME due to having simplicity, recyclability and environmental friendly properties.

PENYEDIAAN, PENCIRIAN DAN APLIKASI NANOKOMPOSIT OKSIDA BESI-KITOSAN SEBAGAI FLOKULAN UNTUK EFLUEN KILANG KELAPA SAWIT

ABSTRAK

Kajian ini bertujuan untuk menyedia, menciri dan menggunakan empat nanokomposit oksida besi-kitosan, iaitu ferrihidrit-kitosan (FC), goetit-kitosan (GC), hematit-kitosan (HC) dan magnetit-kitosan (MC) sebagai flokulan untuk pra-rawatan efluen kilang kelapa sawit (POME). Nanokomposit disediakan melalui kaedah sepemendakan pada tiga nisbah (*w/w*) oksida besi kepada kitosan. Sifat fizikokimia nanokomposit dicirikan dengan menggunakan mikroskop elektron pengimbasan (SEM), spektrometer pembelauan sinar-X (XRD), spektrometer inframerah transformasi fourier (FTIR), magnetometer sampel getaran (VSM) dan penganalisis termogravimetrik (TGA) sebelum dan selepas eksperimen flokulasi untuk membuktikan keberkesanan nanokomposit. Kesan dos flokulan, pH larutan dan masa pengendapan ke atas fokulasi untuk penyingkiran jumlah pepejal terampai (TSS), kekeruhan, permintaan oksigen kimia (COD), minyak dan gris (O&G) dan nutrien (K, Fe, Mn dan Cu) telah dikaji menggunakan kaedah ujian balang. Dapatan kajian mendapati bahawa nanokomposit MC dengan nisbah 1:1 (*w/w*) menunjukkan peratusan pengurangan bahan cemar yang paling tinggi. Keadaan optimum bagi pengurangan semua bahan cemar dicapai pada dos flokulan 1.5 g/L, pH 5.0 dan pada masa pengendapan selama 60 minit. Di bawah keadaan ini, pengurangan TSS, kekeruhan, COD dan O&G adalah masing-masing 86.79%, 82.61%, 74.28% dan 62.64%. Selepas tiga kitaran proses flokulasi/deflokulasi, nanokomposit MC mengekalkan kecekapan flokulasi dan perolehan flokulan masing-masing dalam julat 66.7-85.7% dan 83-91%. Gabungan peneutralan cas dan titian polimer adalah mekanisme utama interaksi antara nanokomposit dan bahan cemar POME. Kesimpulannya, oksida besi yang digabungkan dengan kitosan telah meningkatkan sifat dan prestasi flokulasi nanokomposit berbanding flokulan konvensional. Implikasinya, nanokomposit oksida besi-kitosan berpotensi bertindak sebagai flokulan altenatif untuk pra-rawatan POME kerana mempunyai ciri-ciri keringkasan, kebolehkitar semula dan mesra alam.

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LIST OF ABBREVIATIONS/SYMBOLS

AOPs	Advanced oxidation processes
APHA	American public health association
BOD	Biochemical oxygen demand
COD	Chemical oxygen demand
CPO	Crude palm oil
DO	Dissolved oxygen
DOE	Department of environment
DSC	Differential scanning calorimeter
EFB	Empty fruit bunch
EQA	Environment quality act
FFBs	Fresh fruit bunches
FTIR	Fourier transform infrared
GHG	Greenhouse gases
GMO	Genetically modified organism
HRT	Hydraulic retention time
MF	Microfiltration
MLVSS	Mixed liquor volatile suspended solids
NF	Nanofiltration
NH_3-N	Ammonical-Nitrogen
O&G	Oil and grease
OPF	Oil palm frond
OPT	Oil palm trunk
PAC	Polyaluminum chloride
PAM	Polyacrylamide
PKC	Palm kernel cake
POME	Palm oil mill effluent

POMS	Palm oil mill sludge
PPF	Palm press fibre
RO	Reverse osmosis
RSM	Response surface methodology
SEM	Scanning electron microscopy
SLR	Sludge loading rate
SS	Suspended solids
TCOD	Total chemical oxygen demand
TDS	Total dissolved solid
TGA	Thermogravimetric analysis
TKN	Total kjeldahl nitrogen
TN	Total nitrogen
TOC	Total organic carbon
TP	Total phosphorous
TS	Total solid
TSS	Total suspended solid
TVS	Total volatile solids
UF	Ultrafiltration
VFA	Volatile fatty acid
VSM	Vibrating sample magnetometer
XRD	X-ray diffraction
°C	Degree celcius
emu/g	Electromagnetic unit per gram
NTU	Nephelometric turbidity units
ppm	Parts per million
rpm	Rotation per minute
g/L	Gram per litter
m^3	Cubic meter

CHAPTER 1

INTRODUCTION

1.1 Research Background

In early 1870, the British government introduced the oil palm tree (*Elaeis guineensis*) natively from West Africa to Malaysia as a decorative plant. Afterwards, palm oil was developed into agricultural crops to reduce dependency on rubber and tin. Historically, commercial palm oil cultivation was first encountered at Tennamaram Estate, Selangor in 1917 and the cultivation of palm oil started to increase rapidly in Malaysia in the early 1960s (Ooi et al., 2014; Awalluddin et al., 2015). This is due to the introduction of the government's agricultural diversification programme for planting palm oil. Thus, the palm oil planted area has expanded remarkably from 54,674 hectares in 1960 to more than 5 million hectares in 2019 (MPOC, 2020).

Palm oil is a monoecious species as both male and female reproductive systems exist on the same plant that can grow up to approximately 10-30 metres tall with an average life span around 25-30 years. The ideal growing condition for palm oil trees was in rainy tropical lowland regions that fall within 10 degrees north/south of the equator, where large scale palm crops can be found particularly in Malaysia and Indonesia (Woittiez et al., 2017). It takes 36 months to start bearing the fresh fruit bunches (FFBs) that can be harvested throughout the whole year. Generally, each tree can produce approximately 10 tonnes of FFBs per hectare weighing between 10 and 15 kg with up to 3000 dark purple fruitlets per bunch. The fleshy fruit of each oil palm is almost spherical or elongated in shape that contains 49% oil in the mesocarp and about 50% in the endosperm (Figure 1.1) (Kwasi, 2002).

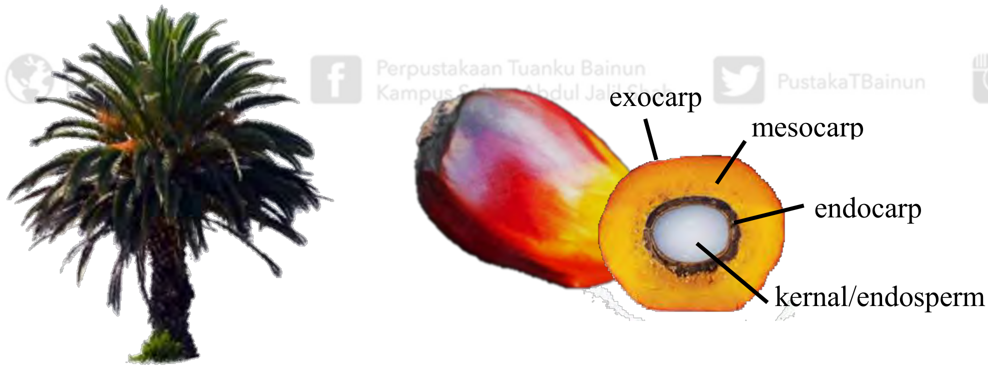

Figure 1.1. The Oil Palm Tree and Structure of an Oil Palm Fruit. Adapted from Kwasi, 2002

Palm fruit produces two different types of oils: (i) palm kernel oil from the seeds and (ii) crude palm oil from the mesocarp. The palm oil company was able to extract 4.0 tonnes of crude palm oil, 0.5 tonnes of palm kernel oil and 0.6 tonnes of palm kernel cake per hectare (Malaysia Palm Oil Board, 2021). Palm oil is the most productive oil crop, which requires less land compared to other oil producing crops. It is estimated that cultivation of oil palm, soybean, rapeseed and sunflower plant is able to produce about 18.5, 0.38, 0.70 and 0.45 tonnes of oil per hectare per year, respectively (Murphy, 2014; Basiron, 2007). The extremely versatile characteristics of palm oil, such as semi-solid at room temperature, resistance to oxidation, longer shelf-life, stable at high temperatures, odourless and colourless make it the most useful and consumed vegetable oil in the world. Nearly 50% of the packaged products we can find in supermarkets, everything from food to personal care products, are mostly produced from oil palm (World Wildlife Fund, 2020). In addition, oil palm is entirely free of genetically modified organisms (GMO), cholesterol and trans-fatty acid (Dian et al., 2017).

Thus, the palm oil industry in Malaysia has grown rapidly with the total production of crude palm oil in 2019 and 2020 reported as 19,858,367 and 19,140,613 tonnes (Malaysia Palm Oil Board, 2021), respectively, and it has made a significant contribution to economic growth in Malaysia and also plays a key component in rural development. In recent years, Malaysia's government has introduced B10 biodiesel that contains 10% of palm methyl ester blended with 90% of petroleum diesel for transportation, which will increase the production of palm oil products annually. Also, the use of the B10 for all types of diesel vehicles shows a reduction in the emission of greenhouse gases by 1.6 million tonnes of carbon dioxide per year said by the 7^{th} prime minister of Malaysia Tun Dr. Mahathir Mohammad (Ministry of Plantation Industries and Commodities (MPIC), 2020). According to the data released by the United States Department of Agriculture in 2020, the world's palm oil production has recorded Indonesia as a major producer of palm oil with a production percentage of 58% followed by Malaysia (29%), Thailand (4%), Columbia (2%), Nigeria (1%) and others (6%) as shown in Figure 1.2. Other countries that have not been mentioned in

Figure 1.2 were Ecuador with annual production of 560,000 tonnes, Honduras (545,000 tonnes), Papua New Guinea (522,000 tonnes), Ghana (520,000 tonnes) and Guatemala (515,000 tonnes).

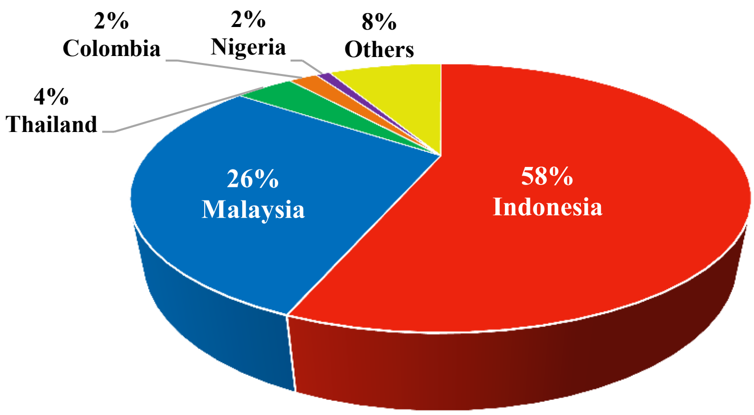

Figure 1.2. The Global Production of Palm Oil in 2020. Adapted from United States Department of Agriculture, 2021

The production of crude palm oil for 2020 by the states in Malaysia is shown in Figure 1.3, in which approximately a total of 19,140,613 tonnes of crude palm oil was produced annually on 5,900,157 hectares of land in Malaysia (Malaysian Palm Oil Board, 2021). However, with the rapid development related to the palm oil industry, the enormous amount of brownish effluent known as palm oil mill effluent (POME) has consequently created significant environmental pollution when released into rivers and lakes without proper treatment. It was estimated that almost 14 million tonnes of POME were generated annually from the processing of crude palm oil in Malaysia, since the production of each tonne of crude palm oil normally produces around 0.67 tonnes of POME. From the production of palm oil, approximately more than 50% of the water that is used in the process will end up as POME (Aris et al., 2017; Wu et al., 2010).

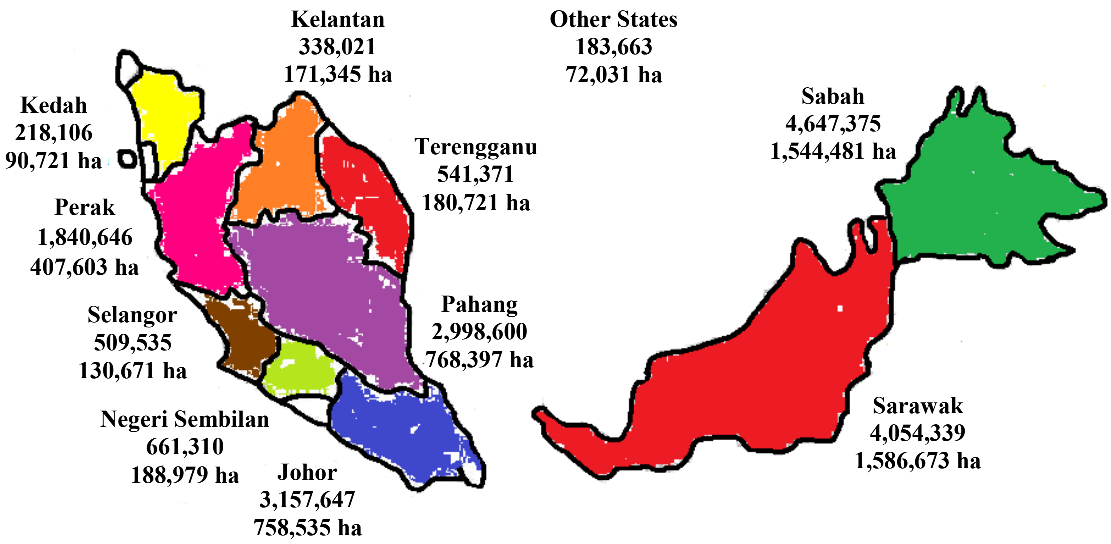

Figure 1.3. Crude Palm Oil Production (Tonnes) and Palm Oil Planter Area by States in Malaysia for 2020. Adapted from Malaysian Palm Oil Board, 2021

Therefore, various methods and technologies have been developed in order to alleviate environmental pollution caused by POME. In this context, treatment techniques such as membrane separation, absorption, coagulation and flocculation based on natural substances have received great attention from scientists. Awareness of environmental protection and sustainable development among the scientific community has developed progressively, which has led to a significant change in research trends worldwide. Researchers are now focusing on the development and application of environmentally friendly materials to remediate environmental issues. This scenario can be proven by the increase in the number of publications and patents filed by researchers, particularly on studies related to natural substances and ecofriendly materials. In fact, these materials were reported to have commercial value and be able to compete with existing synthetic materials available in the market (Chmielewská, 2019).

Studies related to chitosan-based materials have become one of the main focuses of developing environmentally friendly materials. Chitosan and chitin are known to have outstanding properties, such as biocompatibility, biodegradability, non-toxic, and non-allergenic, while possessing some unique properties like film forming ability, chelation and absorption properties, as well as antimicrobial characteristics. In the near decades, various applications of chitosan for the environment have been reported practically in water treatment (Brion-Roby et al., 2018), food preservation (Halim et al., 2018), pesticide (Yusoff et al., 2018), fertiliser (Franca et al., 2018), soil remediation (Tripathi et al., 2018) and air pollution (Yang et al., 2019). Chitosan contains a large number of amino and hydroxyl groups, which are important for chelating effects. This makes chitosan a promising coagulant or flocculants in water treatment.

As for iron based nanoparticles, they have recently also shown outstanding adsorption capacity for removing heavy metals, dyes, inorganic and organic compounds. This is due to their amazing properties such as larger specific surface area, high porosity, strong magnetic response, biocompatibility and reusability, which result in an extraordinary sorption capacity. Also, it can coordinate with other elements due to variable oxidation states. Over the past two decades, the outstanding performance and advantages of using iron oxide nanoparticles have been gaining the attention of research society in solving the environment related problem. The capability of pure chitosan and iron based materials in coagulation and flocculation in wastewater treatment is undeniable, but it has some drawbacks in terms of removing the flocs after the treatment process and iron oxide tends to aggregate due to their large surface-to-volume ratio and low surface energy. Moreover, the pure iron oxide nanoparticles have high chemical activity, and are easily oxidised in the air (especially magnetite), generally resulting in loss of magnetism and dispersibility. Therefore, providing proper surface coating and developing some effective protection strategies to maintain the stability of magnetic iron oxide nanoparticles is very important. Practically, it is worthwhile that in many cases, the protecting shells not only stabilise the magnetic iron oxide nanoparticles, but can also be used for further functionalisation (Wu et al., 2008).

Therefore, an iron oxide-chitosan nanocomposite consists of two major components, namely inorganic iron oxide and organic chitosan will be studied to ensure the stability of the particle and overcome the drawback. Generally, approaches to iron oxide-chitosan nanocomposite have also been accomplished by many researchers because of their benefits in treating wastewater. The nanocomposites have a great potential to be applied in flocculation systems due to easy recovery from aqueous solutions just by applying a magnet, and therefore they could be used repeatedly (Liu et al., 2008). They possess the desired mechanical strength and chemical stability, a fast adsorption rate and are environmentally friendly.

1.2 Problem Statement

The palm oil tree, scientifically known as *E. guineensis*, is one of the world's fastest growing and most profitable crops, particularly in Indonesia and Malaysia. This is because both countries experience a variety of weather conditions throughout the year that are advantageous for palm oil cultivation (Rupani et al., 2010). According to a statistic provided in 2014 by Sime Darby, palm oil recorded the highest consumption of oils and fats in the world when compared to oils and fats derived from other sources, as depicted in Figure 1.4 based on statistics released by the Oil World Organization (2013).

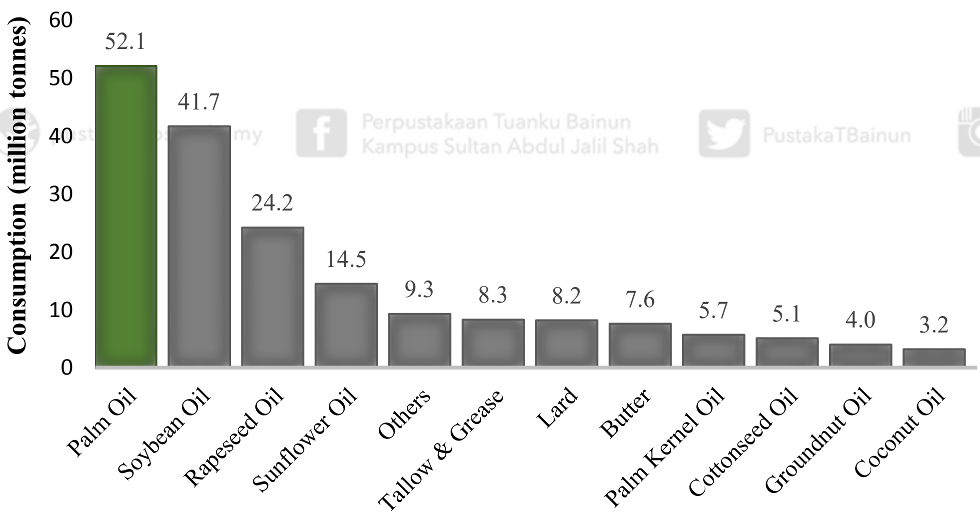

Figure 1.4. Bar Chart Oils & Fats: World Consumption in 2012. Adapted from Sime Darby, 2014

Malaysia is one of the world's leading palm oil producers and exporters, contributing to 29% of world palm oil production and 34% of world exports in 2019 (United States Department of Agriculture, 2021). In addition, the MPOB revealed that the number of palm oil products exported in 2019 increased by 11% or 1,981,712 tonnes, as compared to the previous year's figure of 16,487,546 tonnes. With the expansion of the palm oil industry, the world's production of POME has increased to 184 million tonnes per year, while in Malaysia alone, approximately 53 million tonnes of residues from palm oil trees are produced each year, with the production of residues expected to grow by 5% per year in the future (Mohammed et al., 2011).

It is estimated that the palm oil industry in Malaysia produced more than 26.7 million tonnes of biomass and more than 30 million tonnes of POME in 2005. (Abdulrahman & Azhari, 2016; Yacob et al., 2006). Approximately 28.8 m^3 of biogas containing both methane (CH_4) and carbon dioxide (CO_2) was also produced for every tonne of POME digested, with the predicted CH_4 gas output reaching 0.505 million tonnes by 2020 and the carbon dioxide emissions increasing by 29% every year thereafter (Ahmad & Ghufran, 2018). However, the production of stinky brownish POME will increase inexorably in response to the global demand for palm oil-based products, which will continue to rise.

If the discharge and disposal of POME or by-products into water streams are not adequately handled, they can cause major water pollution, pose a health concern to humans, and create a nuisance due to an unpleasant odour. POME will turn the colour of water streams brown, make them smell bad, make them slimy, and may kill aquatic species organisms. As a matter of fact, the source of drinking water will be contaminated as a result of the increase in biochemical oxygen demand (BOD) in POME, while the decrease in dissolved oxygen (DO) will occur. This scenario can be explained by the high oxygen consumption of bacteria, which results in a large reduction in the amount of DO present in the aqueous environment. In general, more than 85% of the palm oil mill industries in Malaysia have adopted the conventional technique of treating POME, which is based on a ponding system, for this purpose (Zainal et al., 2017). However, when it comes to treating POME, the ponding system has several shortcomings or weaknesses, which are as follows:

i. consists of a mixing pond, cooling pond, anaerobic pond, facultative pond, aerobic pond, aerated pond and final ponds (final discharge) which require large treatment areas, thus control and monitoring systems are difficult because of the pond size (Iskandar et al., 2018),
ii. requires long hydraulic retention time (HRT) to ensure that all suspended solids will be completely treated before being released to the next stage (Wu et al., 2010),
iii. the formation of scum and accumulation of solid sludge at the bottom of the system pond (Barrios-Hernández et al., 2020). When scum and sludge mix for a long time, it will lower the effectiveness of the system by decreasing the volumetric proportion and requiring long HRT for degradation,
iv. the microbes in charge of waste breakdown are kept in suspension and bubbles rise to the surface of the water that creates an offensive smell (Talaiekhozani et al., 2016; Hassan et al., 2004),
v. in many cases, POME that has been released into the river does not meet the discharge standard (Shahrifun et al., 2015).

Various methods and strategies have been proposed for improving the POME treatment systems based on the ponding system have been developed over the years:

i. Aerobic digestion or treatment by using the fungal *Trichoderma viride* (Karim and Kamil, 1989), *Acinetobacter sp*. (KUL8), *Bacillus sp*. (KUL39), *Pseudomonas sp*. (KLB1) (Bhumibhamon et al., 2002), *Yarrowia lipolytica* (Oswal et al., 2002), and *Saccharomyces cerevisiae* (Najafpour et al., 2005) for the treatment of POME.

ii. The suggested improvements in anaerobic treatment processes for POME include anaerobic suspended growth processes, attached growth anaerobic processes, anaerobic sludge blanket processes, membrane separation anaerobic treatment processes and hybrid anaerobic treatment processes (Poh & Chong, 2009).

iii. The physico-chemical treatment processes for POME include sedimentation, centrifugation, coagulation/flocculation by using chitosan (Tadza et al., 2016), flotation and adsorption by using chitosan (Ahmad et al., 2005).

iv. The membrane filtration process involves ultrafiltration, microfiltration, nanofiltration and reverse osmosis (Ahmad et al., 2003)

It is possible, however, that a lack of skilled workers with a thorough understanding and knowledge of handling POME wastewater using new treatment methods will prevent most of the proposals listed above for improving POME treatment system performance based on a ponding system from being implemented successfully in real-world situations.

1.3 Research Gap

Based on a previous study, numerous significant research gaps have been discovered, notably in the area of POME treatment utilising iron oxide-chitosan nanocomposites that should be addressed. These include the following:

i. Previous studies often reported the use of a particular type of iron oxide-chitosan nanocomposites in the treatment of POME. Several forms of iron oxide-chitosan nanocomposites must be evaluated in order to determine which are the most effective.

ii. Researchers normally conduct flocculation studies only using newly synthesised flocculants. There is a need to evaluate the applicability of the proposed flocculants with commercial flocculants.

iii. Monitoring studies of the effluent is necessary before conducting the treatment. There is a need to understand the behaviour of the effluent parameters toward climate change. Because Asia's countries, particularly Malaysia and Indonesia, will have wet and dry seasons throughout the year.

iv. The mechanism involved between contaminants in palm oil mill effluent and composites in some research studies has rarely been mentioned. There is a need to elucidate the flocculation mechanism(s) involved.

v. Recycling testing of the flocculants is rarely conducted. It is necessary to investigate the reusability of the flocculants to reduce treatment expenses.

1.4 Research Aim and Objectives

The aim of the study is to develop environmental friendly flocculants based on iron oxide-chitosan nanocomposites for palm oil mill effluent treatment. The specific objectives of this study are:

i. To prepare iron oxide nanoparticles and iron oxide-chitosan nanocomposites using simple precipitation methods.
ii. To characterise the physico-chemical properties of iron oxide nanoparticles, iron oxide-chitosan nanocomposites using a scanning electron microscope, energy dispersive X-ray spectrometer, X-ray diffraction spectrometer, Fourier transform infrared spectrometer, vibrating sample magnetometer and Raman spectrometer.
iii. To evaluate the magnetic iron oxide-chitosan nanocomposites' efficiency as flocculants for POME treatment using jar test method.
iv. To elucidate the flocculation mechanism involved between contaminants in palm oil mill effluent and iron oxide-chitosan nanocomposites using spectrometry method.

1.5 Significance of the Study

On a global scale, Malaysia is one of the world's largest producers of palm oil in general. Without a doubt, this industry has generated a significant amount of POME as a result of the palm oil extraction process, which has contributed to the water pollution problem. It has been predicted that if palm oil producers do not take appropriate measures, the situation will deteriorate significantly. A variety technologies, procedure, and research have been done to treat POME before it is discharged into a public watercourse. However, these conventional methods appear to be insufficient and expensive, and the complexity of wastewater treatment system disposal has become a serious barrier for the industry in which they are used.

In addition, Malaysia's fisheries industry is one of the most important sectors of the country's food supply, which greatly contributed to 201,898 tonnes of global aquaculture production of fish, crustaceans, and molluscs in 2016. (Food and Agriculture Organization of the United Nations, 2018). POME treatment using chitosan or chitosan-based material is thought to be a low-cost alternative because the source of producing chitosan from chitin is abundant (Saifuddin & Dinara, 2011). Also, the advantage of using chitosan in the pre-treatment of POME is chitosan could act as natural antimicrobial agents to kills microorganisms or stops their growth in wastewater (Yilmaz Atay, 2020). Thus, chitosan incorporating into iron oxide nanoparticles could improve the magnetic properties, thermal properties and biocompatibility, extend its stability and improve the treatment efficiency. Interestingly, treatment of POME utilising iron oxide-chitosan nanocomposites as flocculants have been reported as one of the solutions to manufacture more environmentally friendly materials because they may be recycled and re-used after being treated (Hui et al., 2018). The unique of surface to volume ratio of the nanocomposite has enhanced the ability in term of separation (magnetic properties) and performance of the material (Kamalzare et al., 2021).

Therefore, the knowledge and understanding gained from this recent discovery will be applied to the development of methods for the production of magnetic iron oxide-chitosan nanocomposites and the evaluation of their characterization in the treatment of POME through the use of the flocculation process. In addition, this study was devised to reduce the number of ponds and the retention time it takes for the existing POME treatment to be completed, which will undoubtedly result in a significant improvement in the overall performance of the wastewater treatment system. As a result, Malaysians are able to research and develop new technologies that will be used in Malaysia in the near future, namely the application of chemical flocculation pre-treatment in the POME treatment systems.

1.6 Limitation of the Study

A typical indirect measure of organic matter, biochemical oxygen demand (BOD) indicates the quantity of oxygen consumed by microbes to biologically oxidise organic compounds in aerobic circumstances in the dark at 20 °C over three days. The BOD parameter, on the other hand, will not be examined in these flocculation tests. The BOD/COD ratio, often known as the biodegradability index, has been widely employed as an indication of biodegradation capability in various applications. In accordance with the literature (Table 2.1), the biodegradability index of POME wastewater measure is approximately 0.62, indicating that the COD value of POME is significantly higher than the BOD value, suggesting the existence of large amounts of organic compounds that are not easily degradable in the environment. The BOD/COD ratio for untreated wastewater is measured using the ratio index. If the BOD/COD ratio is greater than 0.5, the waste is regarded to be easily treatable by biological means.

As a result, testing on BOD will be overlooked in this research, with the emphasis being placed on other target pollutants and contaminants in POME treatment. It has been demonstrated that the current biological ponding system shows with using only an anaerobic process results in significant BOD reduction of up to 90% with hydraulic retention times greater than 45 days, depending on the size and depth of the pond (Akhbari et al., 2020)

1.7 Thesis Organisation

Prior to this section, fundamental facts on palm oil, unfavourable environmental issues associated with POME, and the inefficiency of conventional POME therapies are explored, all of which lead to the current investigation. This chapter also includes information about research gaps, research significance, research goals, and the project's overall mission.

The second chapter is a review of the literature on the theoretical basis, which is based on past research that has been collected from numerous journals and the internet. Comprehensive information on POME, regulatory controls over wastewater discharge, current POME treatment systems in Malaysia, factors impacting ponding treatment, remediation techniques for POME, flocculation, chitosan, and iron oxide nanoparticles will be covered in this chapter. Furthermore, the final section in the chapter will discuss nano-based materials that are employed as flocculants in the water treatment industry.

The materials and methods utilised to synthesise iron oxides and iron oxide-chitosan nanocomposites are discussed in detail in Chapter 3, which is a list of materials and procedures. The method for characterising flocculants, as well as jar test experiments with various parameters and water quality analysis of POME used in this study, are all included in this chapter as well.

The results of the physico-chemical characteristics of iron oxide nanoparticles and also the iron oxide-chitosan nanocomposites before and after POME treatment are presented in Chapter 4, as well as the proposed mechanisms involving the composite and POME wastewater. This chapter also explored the efficacy of flocculants in the removal of COD, TSS, turbidity, O&G, and nutrient (K, Fe, Mn and Cu), among other contaminants. The effectiveness studies of flocculants for the treatment of POME are also discussed in this part, with a comparison between synthesised, precursor material (chitosan and iron oxide nanoparticles) and traditional flocculants being conducted. The regeneration and recycling tests for the composite will also be examined in the final section of this chapter for a total of three cycles.

Finally, in Chapter 5, the conclusions obtained from the findings of the current study are presented, and recommendations for future research are made to further improve the findings.