PALM OIL MILL EFFLUENT TERTIARY TREATMENT USING FERROUS SULPHATE

by

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LIST OF ABBREVIATIONS

BOD	Biochemical Oxygen Demand
CAPEX	Capital Expenditure
COD	Chemical Oxygen Demand
CPO	Crude Palm Oil
DO	Dissolve Oxygen
DOE	Department of Environment
EQA	Environmental Quality Act
EFB	Empty Fruit Bunch
$FeSO_4.7H_2O$	Ferrous Sulphate Heptahydrate
$FeSO_4,.H_2O$	Ferrous Sulphate Monohydrate
FFB	Fresh Fruit Bunches
KKS	Kilang Kelapa sawit
NH_3-N	Ammoniacal Nitrogen
O&G	Oil and Grease
OPEX	Operating Expenditure
POME	Palm Oil Mill Effluent Treatment
SS	Suspended Solid
TSS	Total Suspended Solid
TS	Total Solid
SS	Suspended Solid
S/m	Siemen/meter

OLAHAN TERTIER EFLUEN KILANG SAWIT MENGGUNAKAN FERUS SULFAT

ABSTRAK

Industri pengilangan minyak sawit mentah menghasilkan air sisa buangan yang mengandungi kandungan enap cemar yang sangat tinggi dan memerlukan kaedah perawatan yang berkesan. Jabatan Alam Sekitar (JAS), Malaysia telah memperketatkan spesifikasi perlepasan air sisa terawat dari kilang sawit untuk mengawal pencemaran. Draf Pindaaan Peraturan Alam Sekitar mengenai Kilang Sawit telah diedarkan untuk semakan awam pada Julai, 2015 dimana tahap perlepasan sisa rawatan kilang sawit akan diperketatkan dari kini pada tahap Keperluan Oksigen Biokimia (BOD) pada paras 100 mg/L akan diturunkan ke 50 mg/L dan seterusnya secara berperingkat ke 20 mg/L, sementara Pepejal Terampai (SS) pula diturunkan dari 400 mg/L ke paras 200 mg/L untuk kilang sawit yang dilesenkan dengan perlepasan air rawatan ke laluan sumber air. Kaedah perawatan tertier fisikokimia adalah merupakan salah satu pilihan tetapi tidak pernah dikomersialkan kerana ketiadaan bahan penggumpal yang murah dan mesra alam. Bahan penggumpal dari Alumina kebiasaannya digunakan untuk olahan air mentah dan air sisa buangan, tetapi ia akan menghasilkan sisa pepejal berjadual yang amat mahal untuk dilupuskan. Ferus sulfat telah digunakan secara meluas di industri olahan effluen tetapi belum pernah digunakan untuk olahan efluen kilang sawit. Ferus sulfat terdapat dalam kuantiti yang tinggi di Malaysia dan pada harga yang rendah. Kajian telah dilakukan menggunakan ferus sulfat untuk perawatan effluen kilang sawit di peringkat primer, sekunder dan tertier dimana ferus sulfat dalam bentuk monohidrat dan heptahidrat telah digunakan. Keberkesanan rawatan telah dijalankan dengan mencairkan sebanyak 50, 100 dan 150

peratus. Keadaan proses seperti suhu, kelajuan pengaduk dan pH telah ditetapkan pada keadaan yang sama. Kajian menunjukkan ferus sulfat monohidrat menghasilkan olahan yang lebih berkesan berbanding heptahidrat. Penggumpalan menggunakan ferus sulfat untuk effluent kilang sawit belum terawat tidak dapat dilakukan kerana sifat kelikatannya yang tinggi. Walau bagaimana pun, ia dapat merawat dan memperbaiki kualiti air terawat diperingkat sekunder dan tertier. Pengurangan aras Keperluan Oksigen Biokimia (BOD_3), Keperluan Oksigen Kimia(COD) dan Pepejal Terampai (SS) melebihi70 peratus untuk kedua-dua peringkat sekunder dan tertier. Diperingkat sekunder, pengurangan BOD_3 dari 700, COD dari 12,000 dan SS dari 10,000 mg/L masing-masing kepada kurang dari 150, 2,500 dan 2,000 mg/L. Diperingkat tertier pula pengurangannya untuk BOD_3 dari 75, COD dari 800 dan SS dari 550 mg/L masing-masing kepada kurang dari 20, 200 dan 200 mg/L. Pematuhan untuk BOD_3 dan SS masing-masing kurang dari 20 dan 200 mg/L dapat dipenuhi apabila kadar ferum sulfat yang digunakan adalah melebihi 1,000 mg/L. Kajian ini juga menunjukkan bahawa ferus sulfat monohidrat adalah lebih berkesan digunakan untuk pengolahan sisa buangan minyak sawit diperingkat sekunder dan tertier berbanding ferus sulfat heptahidrat. Kajian diperingkat makmal telah diskala naikkan ka peringkat loji pandu dengan muatan 7 tan sejam dengan tujuan untuk menilai keupayaan perawatan fisikokimia yang beroperasi secara berterusan. Loji pandu tersebut dibina bersebelahan dengan loji pengolahan tertier secara biologi yang sedia ada di KKS Chersonese, di Parit Buntar, Perak. Loji pandu tersebut mengandungi sistem pengepaman ferus sulfat, beberapa pengaduk setempat, tangki pengenapan dengan tempoh pengenapan selama 3 ke 8 jam dan dua buah penapis pasir. Ferus sulfat pada kadar melebihi 1,000 mg/L dan menggunakan lebih dari satu pengaduk setempat didapati dapat memenuhi had perlepasan pada BOD_3 kurang dari 20 mg/L dan SS kurang dari 200 mg/L. Analisa ekonomi keatas cadangan loji olahan tertier fisikokimia menunjukkan ia adalah lebih berdaya saing jika dibandingkan dengan loji olahan tertier secara biologi. Jumlah pelaburan yang diperlukan untuk loji olahan kilang sawit berskala 60 tan buah tandan segar (BTB) sejam hanyalah disekitar RM0.50 juta dan kos pengoperasian pada RM0.70 per tan BTB berbanding sistem biologi yang memerlukan pelaburan sebanyak RM2.6 juta dan kos pengoperasian melebihi RM2.00 per tan BTB. Dengan itu, sistem yang dicadangkan memberi penjimatan sehingga 70 peratus kos pengoperasian.

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ABSTRACT

The palm oil milling industry produces very strong effluent loads that needs very effective waste water treatment. The Department of Environment of Malaysia (DOE) has progressively imposing more stringent waste water discharge requirements to mitigate the deterioration of the environment. The latest proposal from the DOE was released for public comments in July, 2015 under the Environmental Quality (Prescribed Premises) (Crude Palm Oil Mill) Regulations be imposed from the current BOD of 100 mg/L to BOD of 50 mg/L and gradually to BOD of 20 mg/L, with lower SS from 400 mg/L to 200 mg/l to all palm oil mills that are licensed for final discharge to watercourse. Physicochemical tertiary treatment has always been an option but has not been explored commercially, mainly due to the un-availability of economic and environmental friendly coagulant. Alum based coagulant is commonly in used for water and waste water treatment, but will produce schedule waste sludge that is expensive to dispose. Ferrous sulphate has been in used for industrial waste water treatment but has not been used for palm oil mill effluent (POME) treatment. Ferrous sulphate is abundant in Malaysia and at very competitive price. Study was conducted using ferrous sulphate for POME treatment at all the three stages of POME treatment namely: primary, secondary and tertiary treatment. Two different types of ferrous sulphate, i.e. heptahydrate and monohydrate were evaluated to determine the effectiveness with different dilution of 50, 100 and 150 percent. The process condition such as temperature, stirrer speed and pH are kept constant. Coagulation using ferrous sulphate with raw POME as feed could not be conducted due to its highly viscous characteristic. However, it could improve the treated water quality when applied to the secondary and tertiary stages. The BOD_3, COD and SS reduction at secondary treatment was more than 70% from BOD_3 of below 700, COD of below 12,000 and SS of below 10,000 mg/L to below 150, 2,500 and below 2,000 mg/L respectively. The same impact of treated water quality reduction of more than 70%, with BOD_3 from below 75, COD of below 800 and SS of below 550 mg/L reduced to below 20, 200 and 200 mg/L respectively at tertiary treatment. Compliance to BOD_3-20 and SS of below 200 mg/L was achievable when treated with ferrous sulphate monohydrate at higher than 1,000 mg/L. The study also indicates that ferrous sulphate monohydrate was more effective than ferrous sulphate heptahydrate. The laboratory study was scaled-up to a pilot scale facility with the capacity of 7 tonne/hour in order to evaluate the physicochemical tertiary treatment with continuous operation. The pilot plant facility was located within the existing tertiary polishing plant using activated sludge process at KKS Chersonese, Parit Buntar, Perak. The pilot scale facility consist of ferrous sulphate dosing system, in-line mixers, settling tank with retention time of 3 – 8 hours and two sets of sand filters. Ferrous sulphate dosage at 750, 1,000, 1250 mg/L and in-line mixers of 1 to 4 units were evaluated. Ferrous sulphate at 1,000 mg/L and above and using more than 1 mixers able to meet the BOD_3-20 mg/L and SS of below 200 mg/L. The economic analysis on the proposed tertiary polishing plant shows that the physicochemical system is more competitive when compared with the present activated sludge systems. The expected investment cost is RM0.5 million while the operating cost is RM0.70 per tonne FFB when compared to the existing tertiary polishing plant which cost RM2.6 million and total operating cost of more than RM2.00 per tonne FFB respectively. The proposed system provides an anticipated saving of almost 70%.

CHAPTER ONE

INTRODUCTION

1.1 Background

The palm oil industry in Malaysia has grown immensely in the recent years and accounted for the largest amount of palm oil production in the world since 1960's before taken over by Indonesia in 2006 (MPOB, 2009). Wherein, the production of palm oil superseded soybean oil by 28% of total oil production in 2011. This is because of palm oil has a relatively lower price and higher production oil yield per hectare compared to other oilseeds crops (Biermann *et al.*, 2011; Ahmad *et al.*, 2011). Due to the global demand of palm oil, Malaysia has increased its oil palm plantation and palm oil industry to enhance palm oil production in accordance to the global need. Currently, Malaysia is the second largest palm oil producer and exporter in the world. While Malaysia is boosting the national economy with development palm oil industry, the palm oil industries in Malaysia are generating large quantity of oil palm byproducts during production of palm oil from fresh fruit bunch (FFB) such as palm oil mill effluent (POME), palm kernel shell, empty fruit bunch (EFB) and mesocarp fiber (Beaudry *et al.*, 2017; Krishnan *et al.*, 2016). Among the various palm oil byproducts, POME possess potential challenge to palm oil industry for an efficient treatment prior to discharge into watercourse.

POME is a liquid waste generated during processing FFB for the palm oil extraction. Generally, this effluent is a thick brownish liquid with high chemical oxygen demand (COD), biochemical oxygen demand (BOD), total solids (TS) and suspended solids (SS) (Cheng *et al.*, 2016). The palm oil industry in Malaysia generates huge amount of POME, which is approximately about 0.5 to 0.8 tonnes of

POME for per tonnes of fresh fruits bunch (FFB) processed. In other word, about 2.5 tonnes to 4.0 tonnes of POME are generated for every tonne of crude palm oil (CPO) generation (Cheng *et al.*, 2016). This is because, if this untreated effluent is discharged into sewage without proper treatment, it is certain to cause substantial environmental pollution due to its high BOD, COD, TS and SS contents. Likewise, the high acidity of POME (i.e., pH 4 to pH 5) make its unsuitable to directly discharge in aqueous system (Alhaji *et al.*, 2016). Thus, this huge quantity of POME generation urges to conduct proper waste management implementation in palm oil mills in order to preserve the environment and ecosystem (Alhaji *et al.*, 2016; Biermann *et al.*, 2011). This problem would be more apparent with the growth of palm oil industry and increasing numbers of palm oil mills in Malaysia.

In order to control the industrial pollution in the country, the Department of Environmental (DOE), Malaysia have enforced regulatory control over discharges untreated POME from the palm oil mills under the Environmental Quality (Prescribed Premises) (Crude Palm Oil) Regulations, 1977, which is promulgated under the Environmental Quality Act, 1974. Wherein, it is stated to adhere to prescribed regulations by the palm oil mills prior to discharge palm oil mill effluent into the nearest watercourses with minimize BOD level 100 mg/L and SS level 400 mg/L (Teh *et al.*, 2016). However, the requirement of BOD level in POME to be discharged into watercourse in certain environmentally sensitive areas especially in Sabah and Sarawak has been further stiffened by DOE from 100 mg/L BOD3 to 20 mg/L (Madaki and Seng, 2013). Therefore, a reliable and effective treatment process must be adopted by palm oil mills to achieve this stringent DOE, Malaysia standard requirement on the POME effluent discharge consistently.

Over 85% palm oil mills in Malaysia have employed the most conventional POME treatment method by ponding system due to low operating cost (Madaki and Seng, 2013; Poh and Chong, 2009; Tabassum *et al.*, 2015). The ponding system of POME treatment comprises of de-oiling tank, acidification ponds, anaerobic ponds and facultative or aerobic ponds. The size and the number of ponds are dependent on the capacity of the palm oil mill. Although ponding system is widely utilized by palm oil mills in Malaysia, this treatment method is not encouraged to treat POME due to the number of drawbacks such as lacking of operational control and long retention time for degradation (Tabassum *et al.*, 2015). Moreover, the biogas produced during POME ponding via anaerobic decomposition is not recovered but was allowed to disperse into the atmosphere, which are causing detrimental environment effect. The major biogas produced during anaerobic decomposition of POME ponding is methane, which is highly responsible gas for global warming (Teh *et al.*, 2016).

The POME contains biodegradable elements with a BOD/COD ratio of 0.5, which implies that POME can be treated effectively by the biological means (Poh and Chong, 2009). Further, the high organic contents in POME can be utilized as a good source to generate methane gas via anaerobic digestion, which can be further utilized as an energy source in palm oil mill or supply to the electricity grid. Therefore, the palm oil mills in Malaysia in recent years are producing biogas from POME treatment plant by using biological anaerobic process following by aerobic process for the POME treatment (Ahmad *et al.*,. 2015; Poh and Chong, 2009;). Subsequently, the treated effluent is use in FFB processing or discharge to the waterway or for land application. Nevertheless, the BOD discharge limit have been set by the DOE, Malaysia at 20 ppm, especially for water catchment areas in East Malaysia, has not been achieved consistently by the combination anaerobic and aerobic digestion of POME.

Methane is a greenhouse gas, which is producing in POME's anaerobic digestion and is considered 21 times higher potential than carbon dioxide in trapping heat generation. Therefore, palm oil mills are identified as the second largest source for the greenhouse gas in Malaysia, (38%), which is next to waste landfills (53%). The palm biogas generated during POME digestions is therefore considered as the main contributor to world global warming. Moreover, the biogas generated during biological treatment are corrosive and odorous due to the presence of hydrogen sulphide. Thus, the discharge of biological treated POME to environment can cause detrimental environmental effects. In addition, the biological treatment system requires proper monitoring and maintenance since the processes depend mainly on microorganisms to break down the pollutants. It is well know that the microorganisms are very sensitive for changing in the environment, it is therefore required effective monitoring to ensure a conducive environment is maintained for the microorganisms to thrive (Ahmad *et al.*, 2015).

Numbers of research have been conducted in the last decades to determine an advance POME treatment process for preserving the environment and ecosystem from pollution (Ahmad *et al.*, 2015; Alhaji *et al.*, 2016; Madaki and Seng, 2013; Poh and Chong, 2009; Tabassum *et al.*, 2015). POME treatment requires an effective alternative existing treatment process to meet up existing challenges as well as to meet standard discharge limits. Studies have been conducted to determine an effective alternative of the conventional biological treatment process of POME. However, a technological shift from conventional biological process to physicochemical process, such as treatment of POME with coagulation process using an environmental friendly coagulants could be an effective alternative to meet the existing challenge of POME treatment.

Alum based polymer has been widely utilized as a coagulant to treat wastewater due to its attractive cost (Luo *et al.*, 2014; Teh *et al.*, 2016; Shankar and Shikha, 2017). Unfortunately, this physicochemical process faces difficulties in disposing the produces sludge, as Aluminum based sludge is categorized as schedule waste (Ahmad *et al.*, 2016; Daud *et al.*, 2015; Ashraf *et al.*, 2013; Shankar and Shikha, 2017). Aluminum sulphate, ferric chloride and polyacrylamide have also been utilized as coagulants to minimize COD and BOD level in POME. Although, the removal of BOD and COD gained up to 60 %, but the BOD and COD concentrations in POME is still higher than the level set for POME treatment by DOE, Malaysia. Alternative physicochemical treatment could be utilized by using Iron (II) sulphate as a coagulant. Iron (II) sulphate has been utilized in municipal waste treatment and found to be very effective coagulants to minimize the BOD and COD level in municipal water (Kamali *et al.*, 2016; Suopajärvi *et al.*, 2013). Although, there are few studies have been conducted in POME treatment using $FeSO_4.7H_2O$ as coagulant, but there is no study has yet been conducted to determine the efficiency and economic viability of $FeSO_4.7H_2O$ and $FeSO_4$. H_2O as chemical coagulants.

1.2 Problem statement

Palm oil processing mills generates about 0.67 tonne of POME for every tonne of fresh fruit bunch (FFB) processed, which is generally discharge into nearby watercourse (Liew *et al.*, 2015). The organic components present in palm oil mill effluents might cause detrimental effects to the environment if untreated POME is discharged into the environment (Krishnan *et al.*, 2016; Liew *et al.*, 2015; Poh *et al.*, 2009). The government acted responsibility in endorsing the Environment Quality Act in 1974 with the specific regulations for palm oil mill effluent treatment in 1977. According to the regulation, all palm oil mills are bound to treat the POME on site to minimize the organic pollutants, in particular, COD, BOD and TS level to an acceptable level prior to be discharged into water courses. The palm oil industry are required to obey the prescribed regulations, including the discharge POME into water courses and land (DOE, 1999; Liew *et al.*, 2015). However, the requirement of BOD level in POME to be discharged to ecosystem has been further strengthen in 2005 by DOE, Malaysia, where BOD level of 100 mg/L, which is prevailing the national regulation of Malaysia must be reduced to 20 mg/L for certain environmentally sensitive areas, particularly, in Sabah and Sarawak (Madaki and Seng, 2013; Soleimaninanadegani and Manshad, 2014; Wang *et al.*, 2015). Therefore, a reliable and effective treatment process has to be implemented by palm oil mills to gain this stringent standard requirement by DOE, Malaysia on effluent discharge consistently.

Biological anaerobic process following by aerobic process are the most common treatment method for POME treatment in Malaysia. However, with the BOD discharge limit of 20 ppm has been set by the DOE, Malaysia, especially for water catchment areas in East Malaysia, has not yet to be achieved with the combination of aerobic and anaerobic digestion POME (Liew *et al.*, 2015; Tabassum *et al.*, 2015). Moreover, the biological anaerobic process and aerobic process to treat POME are always being conducted using open ponding or digestion tank systems, which have particular disadvantages such as malodour, long hydraulic retention time and difficulty in maintaining the liquor distribution to ensure smooth performance ((Poh *et.al*., 2015; Wang *et al.*, 2015). Over the last decades, the management of POME has evolved from treatment of the "POME for disposal" to beneficial and utilization of either treated POME and or its by-products (Ahmad *et al.*, 2016; Daud *et al.*, 2015; Kamali *et al.*, 2016).

In chemical precipitation process, the commonly used coagulants in wastewater treatments such as aluminium sulphate (Alum) and polyaluminum chloride (PAC) produce sludge that is difficult to dispose and in terms of health concern can cause Alzheimer's disease in long term effects (Alhaji *et al.*, 2016; Luo *et al.*, 2014). Alum based polymer has been widely utilized as a coagulant to treat wastewater due to its attractive cost (Chew *et al.*, 2016; Meraz *et al.*, 2016; Teh *et al.*, 2016). Unfortunately, this physicochemical process faces difficulties in disposing the produces sludge, as Aluminum based sludge is categorized as schedule waste (Alhaji *et al.*, 2016; Chew *et al.*, 2016). Aluminum sulphate, ferric chloride and polyacrylamide have also been utilized as coagulants to minimize COD and BOD level in POME, but the BOD and COD concentrations in POME was not able comply to regulation set for POME treatment by DOE, Malaysia. Iron (II) sulphate has been utilized in municipal waste treatment and found to be very effective coagulants to minimize the BOD and COD level in municipal water. Although, there is few studies have been conducted in POME treatment using $FeSO_4.7H_2O$ as coagulant, but there is no study has yet been conducted to determine the efficiency and economic viability of $FeSO_4.7H_2O$ and $FeSO_4. H_2O$ as a chemical coagulants.

Although, numerous studies have been conducted to determine an effective POME treatment process, but there are rare studies have been commercially conducted on physicochemical polishing treatment. A pilot scale study of POME treatment will provide exact scenario on POME treatment process parameters and cost involve with treatment process. Therefore, in the present project, ferrous sulphate will be applied for POME treatment due to its abundant availability at much competitive price in Malaysia as by-product from the manufacturing of titanium dioxide. Further, the cost analyses and impact of the ferrous sulphate coagulation process to environment will also be determined.

1.3 Objectives

i. To study palm oil mill effluent (POME) on the removal of BOD, COD and SS using $FeSO_4.7H_2O$ and $FeSO_4.H_2O$.

ii. To compare the efficiency of $FeSO_4.7H_2O$ and $FeSO_4.H_2O$ on the removal of BOD, COD and SS from POME.

iii. To design and evaluate the $FeSO_4.H_2O$ coagulation efficiency at a continuous pilot scale operation on the removal of BOD, COD and SS.

iv. To conduct economic viability of POME tertiary treatment using $FeSO_4.H_2O$ as coagulant.

1.4 Scope of the study

Application of $FeSO_4.7H_2O$ and $FeSO_4.H_2O$ as a new coagulants for the treatment of POME is the main focus of the present study. The Physicochemical properties such as pH, temperature, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solid (TSS), Suspended Solid (SS), Oil & Grease (O&G) Turbidity of Fresh POME from Sludge Pit (Primary POME), anaerobic digester tank for secondary treatment (Secondary POME), First aerobic pond for tertiary treatment (Tertiary POME) were determined. The coagulation tests were conducted following standard practice for coagulation-flocculation testing of industrial wastewater treatment (APHA, 2012) at various coagulation doses

(200mg/L-2000 mg/L), dilution factor (DF) for 60 min with natural pH and temperature. Wherein, the coagulation efficiency of $FeSO_4.7H_2O$ and $FeSO_4.H_2O$ were determined on the removal of BOD, COD, TSS, SS, O&G, Turbidity in treated Primary POME, Secondary POME and Tertiary POME. The coagulation efficiency of $FeSO_4.7H_2O$ and $FeSO_4.H_2O$ coagulants were compared and determine as to which is most suitable for use as coagulant and its optimal experimental conditions. Subsequently, the coagulation of POME was conducted in pilot scale using the optimal experimental conditions of $FeSO_4.H_2O$ coagulant (coagulant doses of 750 mg/L -1250 mg/L; natural pH, ambient temperature, reaction time 3 h). Finally, the economic viability of the $FeSO_4.H_2O$ coagulation of POME was determined and compared with the existing POME tertiary treatment cost.

CHAPTER TWO

LITERATURE REVIEW

2.1 Palm Oil Mill Effluent

Oil palm is one of the world's most rapidly growing crops as in Malaysia. Malaysia is the second largest palm oil producing countries after Indonesia. Malaysia has a tropical climate, which is favorable weather for oil palm plantation. Currently, oil palm plantation occupies the largest acreage of cultivated land in Malaysia (Abdul-Manan *et al.*, 2014; Cock *et al.*, 2016; Hoffmann *et al.*, 2017). In the year 2016, there were more than 5.74 million hectares of land under oil palm cultivation in Malaysia, occupying over one third of the total cultivated land of Malaysia (MPOB Statistics, 2016). Palm oil is an edible oil, which is obtained from the fleshy mesocarp of the oil palm fruits. One hectare of oil palm plantations in Malaysia produces 10-35 tons of oil palm fruits (FFB). The oil palm has a lifespan of over 200 years, while the economic life is 20-25 years, nursery period is 11-15 months and the first harvesting time is 32-38 months after planting (Katheem *et al.*, 2016). The duration for peaking yield of FFB is about 15-20 years. The yield of palm oil from the fleshy mesocarp of the oil palm fruit is about 18-23 % of fresh fruits bunch (FFB) with the palm kernel yield at 3.5-6.0% of FFB, wherein the yield of palm kernel oil from the palm kernel is about 42-47%. Generally, one tonne of crude palm oil (CPO) can be obtained from 5.0 tonnes of FFB (Abdul-Manan *et al.*, 2014).

The extraction of CPO from the FFB generates large quantities of liquid waste, which is generally referred as palm oil mill effluent (POME). The POME generation is approximately 60-80 wt% of FFB, which is a colloidal suspension that contains water, oil, total suspended solids (TSS), total solids (TS), some protein and carbohydrate (Ahmad *et al.*, 2015; Hosseini & Abdul Wahid, 2015). The FFB undergo steam sterilization prior to further processing towards palm oil extraction. The purpose of steam sterilization is to prevent free fatty acids formation due to enzymatic action and to facilitate stripping of palm fruits from FFB and to condition the fruits for oil extraction. After sterilization, the FFBs are fed to a rotary drum-thresher to strip the oil palm fruits from FFB. Subsequently, the detached fruits are collected and discharged into a digester.

Figure 2.1. Typical palm oil mill at Sime Darby Plantation - KKS Sua Betong, Port Dickson, Negeri Sembilan.

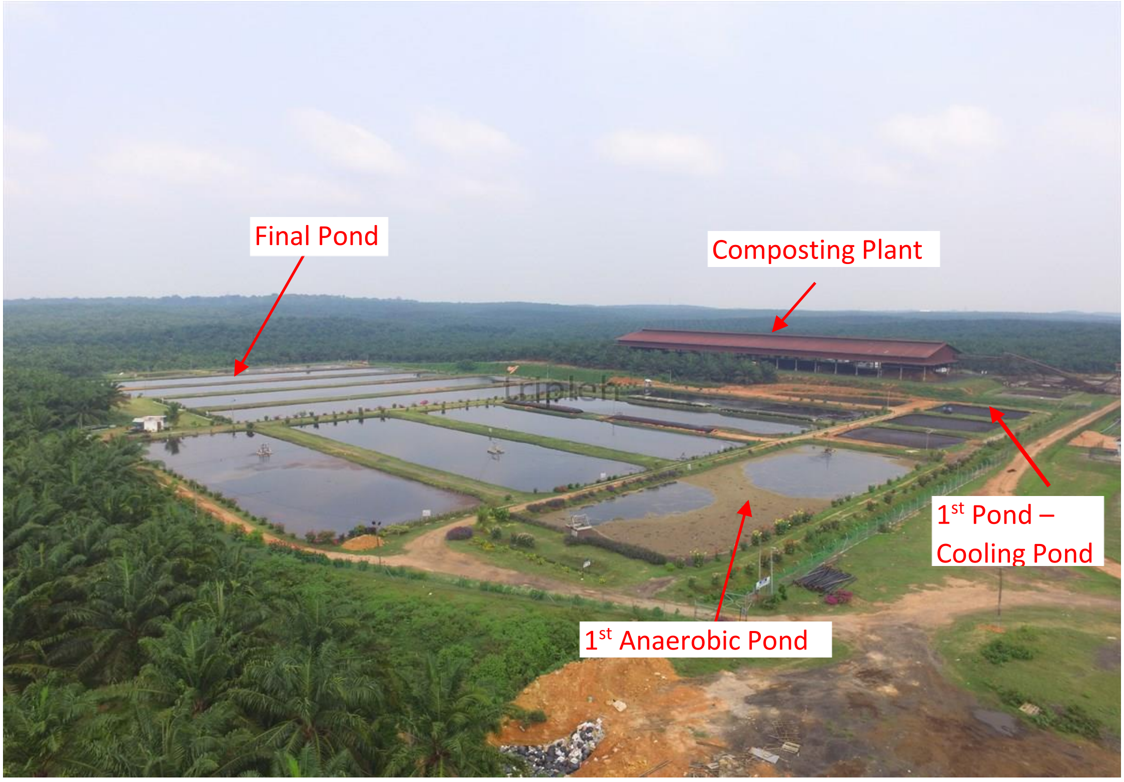

Figure 2.2. Typical Effluent Treatment Plant with Composting Plant at KKS Sua Betong, Port Dickson, Negeri Sembilan.

In the digester, the fruits are mashed by the rotating arms under heating to break the oil-bearing cells of the mesocarp. Twin screw press method is generally utilized to extract oil from the digested mash of oil palm fruits under high pressure. Hot water is added to increase the flow of the oils by reducing its viscosity that will later ease the oil recovery during clarification. The crude oil slurry is then transferred to the oil clarification system for separation and purification. The obtained CPO from the screw presses consists of a mixture of palm oil (35-45%), water (45-55%) and others fibrous materials in varying proportion. The CPO is then pumped into a horizontal or vertical clarification tank for oil separation. In this unit, the clarified oil is continuously skimmed-off from the top of the clarification tank. Then, it is passed through a high speed separator and a vacuum dryer before sending to the storage tanks. The remaining oil in the sludge from the clarifier underflow is recovered using sludge centrifuge or decanter which then returned to the clarifier. The fiber and nuts are separated by a winnowing. Meanwhile, the nuts are sent to a rotating drum where any remaining fiber is removed before they are sent to a nut cracker. Majority of the shell is separated from kernel using winnowing method while the remaining by using hydrocyclone or claybath. The discharge from this process constitutes the last source of wastewater stream.

The principle source of POME generation during oil palm processing for palm extraction in oil palm mills is shown in Figure 2.6. There are three principle sources of POME generation in an oil palm mill such as sterilizer condensate (generates about 25% of total POME during sterilization of FFB), clarification wastewater (about 65% of total POME generated during clarification of the extracted CPO) and shell-hydrocyclone wastewater (about 5% of total POME generated during clay bath separation of cracked mixture of kernel) (Liew *et al.*, 2015). There are other minor sources for POME generation including turbine cooling water and steam condensates, boiler blow-downs, overflows from the vacuum dryers and some floor washings that contributes for another 5% of the total POME. The volume of the combined POME discharged depends to a large extent on the milling operations. POME is a non-toxic wastewater as there is no chemical required during the palm oil extraction process (Manickam *et al.*, 2014). It is estimated that 5 to 7.5 tons of water are required for producing 1 tonne of crude palm oil, where over 50% of the water treated as POME (Ahmad *et al.*, 2016). The typical POME produced is in the range of 0.60 to 0.80 over FFB. Althoughpalm oil industry has given noteworthy economic benefits to the palm oil producing nation, the adverse environmental impacts arise by the palm oil industry with generating huge amount of POME cannot be ignored. High COD, BOD, oil and grease content of POME bear an important consideration in the safe handling and treatment (Manickam *et al.*, 2014). It requires effective treatment method to remove the pollutants in order to prevent interfaces in water treatment units, avoid problems in biological treatment stages, reduce fouling in process equipment and comply with water discharge requirements (Ahmad *et al.* 2016).

2.2 POME generation in Malaysia

The generation of the liquid wastewater production in results of FFB processing towards palm oil production is referred as POME. There are currently 439 palm oil processing mills are in Malaysia (MPOB, 2015). Huge amounts of POME are generating with the palm oil industries, which can be potential threat to water bodies if not properly treated. According to Yacob *et al.* (2005), about 30 million tons of POME were generated by 381 palm oil mills in Malaysia in 2004. However, POME generation was increased with increasing CPO generation in 2005. Based on palm oil production in 2005, an average of 53 million m^3 POME is being produced per year in Malaysia (MPOB, 2009.). Certainly, the amount of POME generation increased with increasing CPO production by the Malaysian palm oil industries at the rate of three to four times of the CPO produced, and the scenario will continue with the rising demand of CPO production to meet both domestic and global demand.

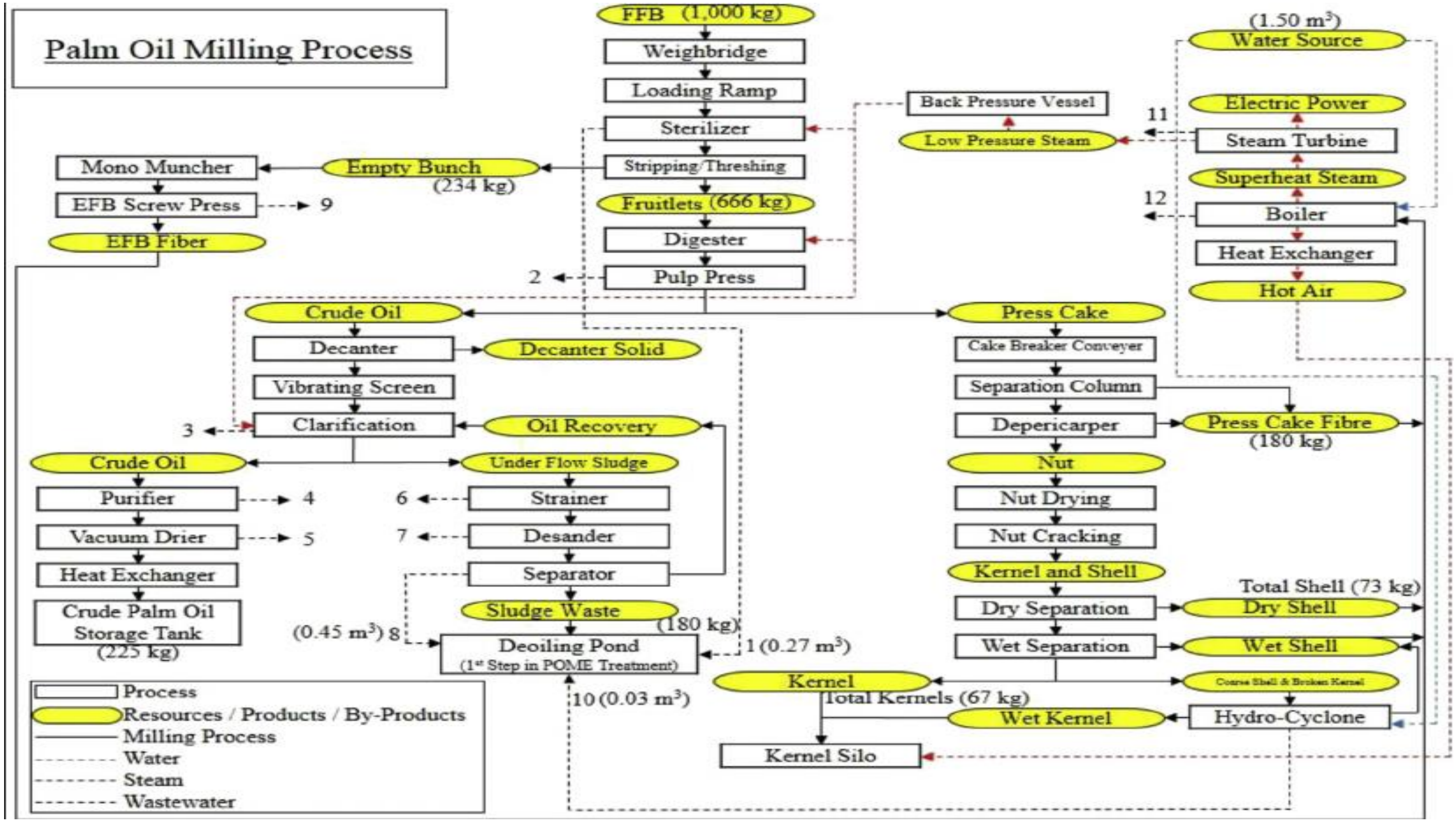

Figure 2.3. Process flow diagram of oil extraction from oil palm and POME generation (Source: Sime Darby Research Sdn Bhd, Malaysia)

It was estimated about 57 million m^3 POME production in 2013 from 434 Malaysian palm oil industries (Kumaran *et al.*, 2016). Figure 2.7 reveals the POME generation based on daily CPO production in Malaysia. As can see in Figure 2.7, with the increasing POME generation trend, it is estimated that over 68 million m^3/day POME will be generated with rising CPO production by Malaysian palm oil industries by the year 2020.

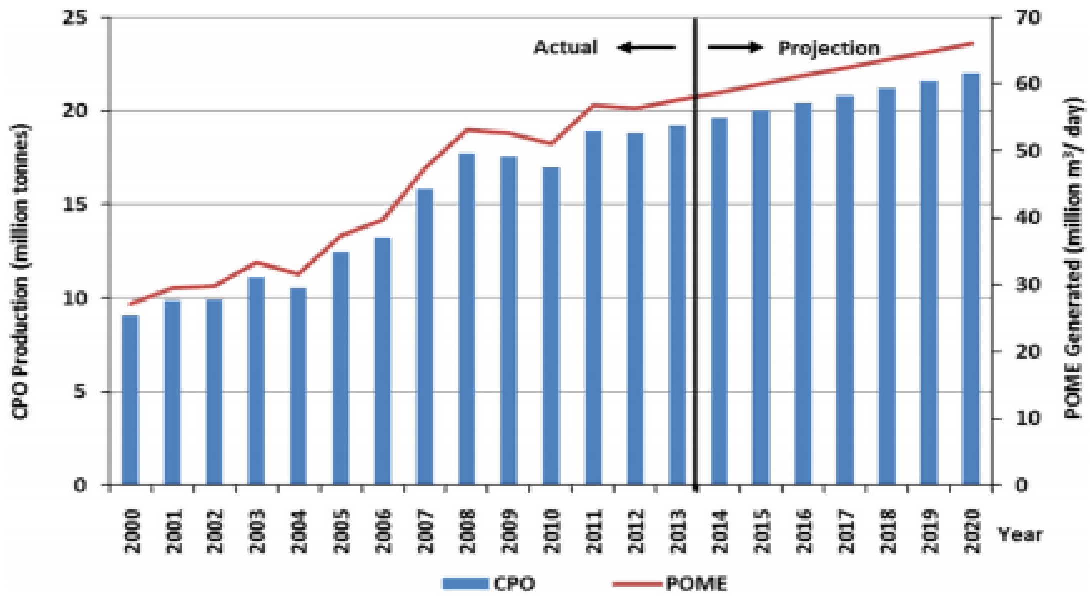

Figure 2.4. Estimated POME generation based on the CPO production in Malaysia in 2004–2020 (Adapted from Kumaran *et al.*, 2016).

2.3 Physicochemical characteristics of POME

POME comprises a combination of the wastewater streams which are principally generated and discharged from Sterilization of FFB, Clarification of the extracted CPO and Hydrocyclone or Claybath separation of cracked mixture in a ratio of 9:15:1 (Wu *et al.*, 2010). Generally, the physicochemical characteristics of POME might vary with many factors including oil palm processing techniques, age or types of fruits, climate, effluent discharge limits set by the palm oil mill and conditions of the palm oil processing (Ahmad *et al.*, 2016; Wu *et al.*, 2010). Physicochemical characterization of Palm Oil Mill Effluent (POME) is presented in Table 2.3. Yacob *et al.* (2006) observed that activities of palm oil mill (operation and quality control of the individual mill, closure of the mill, etc.) and seasonal oil palm cropping influences the quality and quantity of POME, which may further affect the treatment process of POME. Ahmad *et al.* (2005) reported that the composition of POME mainly depends on raw material quality, season and the particular operations being used at any given time.

POME is a combination of oil and fine cellulosic fruit residues in water. Fresh POME is a thick brownish in color. POME is slightly acidic with a pH between pH 4 to pH 5 and the temperature of between 80°C and 90°C when discharged (Krishnan *et al.*, 2016). The physicochemical characteristics of a fresh POME are presented in Table 2.1. POME has a very high Chemical Oxygen Demand (COD, ≥ 50,000 mg/L) and Biochemical Oxygen Demand (BOD, 25,000 mg/L), total solids (40,500 mg/L), oil and grease of higher than 4,000 mg/L, which is 100 times higher than the municipal sewage (Abdullah *et al.*, 2015). It is a non-toxic and biodegradable waste. Generally, fresh POME is a colloidal suspension, which contains of water (95–96 wt%), oil and grease (0.6–0.7 wt%) of and total solids (4–5 wt%). Among the total solid, 2-4 wt% is suspended solids that is initiated from the mixture of sterilized condensate, sludge centrifuge or decanter and hydrocyclone wastewater (Alhaji *et al.*, 2016). The oil and grease content in POME about 4000–10,000 mg/L. The oil droplets of POME are distributed in two phases either float on the upper layer of the suspension or suspend in the supernatant. The solvent extractable oil droplets of POME consists of 84 wt% neutral lipids and 16 wt% of complex lipids (6 wt% glygolipids and 10 wt% phospholipids) (Chooklin *et al.*, 2013).

Table 2.1. Physicochemical characterization of raw Palm Oil Mill Effluent (Source: Abdullah *et al.*, 2015; Alhaji *et al.*, 2016)

Parameters	**Unit**	**Value**	**Regulatory discharge limits for BOD 100***
pH	-	4.0-5.0	5.0-9.0
Temperature	^{o}C	45	
BOD	mgL^{-1}	25000	100
COD	mgL^{-1}	50000	**
Total Solids	mgL^{-1}	40500	**
Suspended Solids	mgL^{-1}	18000	400
Total Volatile Solids	mgL^{-1}	34000	
Ammonical Nitrogen	mgL^{-1}	35	150
Total Nitrogen	mgL^{-1}	750	200
Oil and Grease	mgL^{-1}	4000–6000	50

* Regulatory standards for POME–Standard E (Environmental Quality Act 2005); **No discharge limits after 1984.

Characteristics of individual waste water streams is presented in Table 2.2. As stated earlier, POME when fresh is a thick brownish colloidal mixture of water, oil and fine suspended solids. Ma *et al.* (2000) reported that POME is non-toxic, as no chemicals are added during the extraction process. However, POME is acidic in nature with pH about 4.5, with the low pH in POME is due to the natural characteristic of the oil palm fruit juice generated during the pressing that is acidic in nature (Budiman *et al.*, 2014). Wu *et al.* (2010) reported that POME consist of water soluble constituents of oil palm fruits and suspended materials like, short palm fiber, oil residues cell walls, carbohydrates, organelles, nitrogenous compounds (proteins to amino acids, mineral constitutes and organic acids. The nutrients constitutes in POME are vital nutrient elements for plant growth, such as magnesium, nitrogen, phosphorus, potassium and calcium. Studies also reported the presence of heavy metals such as aluminum and lead (Wu *et al.*, 2006). However, the detected heavy metals concentration are usually below the lethal levels (> 17.5 ug/g). Katheem *et al.* (2016) reported that the present of lead in POME as a result of contamination with paints and glazing materials of plastic, metal pipes, tanks and other containers used in FFB processing towards palm oil extraction.

Table 2.2 Characteristics of individual waste water streams (Source: Chooklin *et al.*, 2013; Madaki and Seng, 2013)

Parameters	**Sterilizer condensate**	**Sludge Centrifuge/decanter heavy phase**	**Hydrocyclone/Claybath**
pH	5.0	4.5	-
BOD	23000	29000	5000
COD	47000	64000	15000
SS	5000	23000	7000
TS	34000	22000	100
NH_3-N	20	40	-
Total Nitrogen	500	1200	100

2.4 Regulatory Control of Effluent Discharge

The quantity of POME generation by the palm oil mills in Malaysia can be accounted averaged up to 161,000 m^3/day, wherein the total BOD load in generated raw POME is about 4,025 tons/day (Madaki and Seng, 2013). The above statistics indicate that if the entire palm oil industry discharges untreated or partially treated POME into the nearby watercourse and undergoes natural decomposition, the dissolved oxygen of the watercourse might depleted (Katheem *et al.*, 2016). The palm oil present in the untreated POME would float on the surface of the waterbody in the form of wide-spread film, which can competently avert atmospheric oxygen from dissolving into the water. Besides, untreated or partially treated POME discharge into