Water quality assessment and a study of current palm oil mill effluent (POME) treatment by ponding system method

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Abstract. Palm oil is one of the main drivers of Malaysian economy that becomes major contributor to the Malaysian Gross Domestic Product (GDP) in the agriculture sector. The demand for palm oil-based product is expected to increase proportionally to the growing population, thus palm oil plantations have been growing rapidly to meet the global demand. Hence, to ensure sustainable management of palm oil production, avoid a significant effect to environmental pollution, the Roundtable on Sustainable Palm Oil (RSPO) and Malaysian Sustainable Palm Oil (MSPO) have been established to minimize environmental issues related to the palm oil industry in Malaysia. This paper provides the physicochemical characteristics and treatment techniques currently available for treating palm oil mill effluent (POME) nowadays. In addition, the correspondence between biological oxygen demand (BOD) and suspended solid (SS) of raw POME samples with the rainfall distribution pattern were also evaluated. The sampling took place at the cooling pond of a palm oil mill throughout 2019 and had been analyzed using water quality standard methods. The results indicated that the total monthly rainfall significantly influenced the concentration of BOD and SS parameters, of which in dry season (February) the highest BOD (36,200 mg/L) and lowest SS (10,522 mg/L) were recorded.

1. Introduction

In early 1870, the British government was introduced the palm oil tree (Elaeis guineensis) natively from West Africa to Malaysia for landscape decorative purposes. Afterwards, the palm oil tree was developed as an industrial crop to reduce dependency on rubber and tin. Historically, commercial palm oil cultivation was first encountered at Tennamaran Estate, Selangor in 1917 and the cultivation had increased rapidly in Malaysia started in early 1960 [1,2]. This is according to the introduction of government’s agricultural diversification program for planting palm oil. Thus, the palm oil planted area was expanded remarkably from 54,674 hectare in 1960 to more than 5 million hectares in 2019 [3].

E. guineensis is a monoecious species as male and female reproductive systems exist together 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 was in rainy tropical lowland regions that fall within 10 degrees north or south of the Earth’s equator, where large scale palm crop can be found particularly at Malaysia and Indonesia [4]. It takes 36 months to start bearing the fresh fruit bunches (FFBs) that can be harvested all year round. Every single tree can produce averagely 10 tonnes of FFBs per hectare weighing between 10 and 15 kg with up to 3000 dark purple fruitlet per bunch. The
fleshy fruit of each oil palm is virtually spherical or elongated in shape that contains 49% oil at mesocarp and about 50% endosperm (figure 1) [5].

Palm fruits generate two different types of oils: (i) palm kernel oil from the seeds/kernel and (ii) crude palm oil from the mesocarp. The palm oil able to extracted 4.0 tonnes of crude palm oil, 0.5 tonnes of palm kernel oil, and 0.6 tonnes of palm kernel cake per hectare [6]. Palm oil is one of the highest yield oil crops, which required lesser land that other oil-producing crop. It is estimated that cultivation average yields of palm oil, soybean, rapeseed, and sunflower, are able to produce about 18.5, 0.38, 0.70 and 0.45 tonnes of oil per hectare per year, respectively [7,8]. The extremely versatile characteristics of oil palm such as semi-solid at ambient temperature, longer shelf-life, stable at high heat, resistant to oxidation, odourless and colourless become the most useful and consumed vegetable oil worldwide. Nearly 50% of the packed products can be found in grocery stores, anything about food to personal care products are mostly produced from palm oil [9]. Palm oil is entirely free of genetically modified organism (GMO), cholesterol, and trans-fatty acid [10].

**Table 1.** The global production of palm oil in 2019 [11].

| Country   | Production (million metric tonnes) | %  |
|-----------|-----------------------------------|----|
| Indonesia | 41.50                             | 58 |
| Malaysia  | 20.80                             | 29 |
| Thailand  | 2.90                              | 4  |
| Colombia  | 1.63                              | 2  |
| Nigeria   | 1.02                              | 1  |
| Others    | 3.17                              | 6  |

According to the data reported by the United States Department of Agriculture in 2020, Indonesia and Malaysia covered over 87% of world supply of palm oil including with other 49 countries (table 1) [11]. The palm oil industry in Malaysia has grown rapidly. The total production of crude palm oil in 2018 and 2019 was reported as 19,515,496 and 19,858,367 tonnes [6], respectively and it has a consequential contribution to economic development and growth in Malaysia. Therefore, this paper will summarize in detail the characteristic of POME and the biological reactions involved in the ponding system, along with the factor that could affect its efficiency. Besides, the observation of water quality in the palm oil mill pond treatment, and studies about the relationship between POME parameter (BOD and SS) and rainfall distribution will also be evaluated.

2. A study of Malaysian palm oil industry

2.1. Palm oil mill effluent (POME)

POME is a liquid waste produced in the extraction process of palm oil. It has been estimated that more than 0.75 m$^3$ of POME will be normally produced for each tonne of FFB production. In 2019, Malaysia produced roughly 19.85 million tonnes of crude palm oil (CPO), expected around 1.5 m$^3$ of water is needed in producing one tonne of CPO and generated close to 14.89 million m$^3$ of POME annually [12,13]. Due to enormous water consumption throughout the palm oil extraction process, thus half amount of it will end up as liquid effluent. They are five major separation stages in palm oil extraction process, namely: (i) sterilisation (created 36% of total POME), (ii) bunch stripping, (iii) digestion and pressing, (iv) oil clarification and purification (60% of POME) and (v) nut cracking (4% of POME) [14].

Generally, the liquid waste from palm oil extraction is non-toxic because there is no chemical addition in the extraction process, and it makes it as the best food source of nutrients for...
microorganisms [15]. The raw or untreated POME has a high amount of nutrient and organic matter. The high total number of organic matter content is due to the existence of different kinds of sugars such as arabinose, xylose, glucose, galactose and mannose, which act as carbon sources to the microbial community [16]. In Malaysia, there are 436 water pollution sources in 2013 contributed by palm oil mills industry as stated in the annual Malaysia Environment Quality Report.

2.2. Characterisation of POME

The characteristics of raw POME are listed in table 2. Generally, the physical of raw or untreated POME is dark-brown colour with a colloidal mixture consisting of 95 to 96% water, 0.6 to 0.7% oil and 4 to 5% total solids including 2 to 4% suspended solid particularly fragments from the palm fruit [17]. It is also acidic because of the organic and free fatty acid production in the fermentation process, it is non-toxic, has a distinctive odor, and is discharged at a temperature between 80-90°C [18].

Fresh POME also possesses a high number of total solids, biochemical oxygen demand, chemical oxygen demand, oil, and grease. The characteristics of POME may vary based on days, factories, batches, processing techniques, the quality or type of fruit, and the chopping season [19].

| Parameters                                | Units | Range          |
|-------------------------------------------|-------|----------------|
| Temperature                               | °C    | 80 - 90        |
| pH                                        | -     | 4 - 5          |
| Biochemical Oxygen Demand (BOD)           | mg/L  | 25,000 - 65,714|
| Chemical Oxygen Demand (COD)              | mg/L  | 44,300 - 102,696|
| Total Solid (TS)                          | mg/L  | 40,500 - 72,058|
| Total Suspended Solids (TSS)              | mg/L  | 12,800 - 18,000|
| Total Volatile Solids (TVS)               | mg/L  | 34,000 - 49,300|
| Oil and Grease (O&G)                      | mg/L  | 145 - 9,341    |
| Ammonical-Nitrogen (NH₃-N)                | mg/L  | 35 - 103       |
| Total Kjeldahl nitrogen (TKN)             | mg/L  | 750 - 770      |

Moreover, POME is known as an effluent that contains high composition and concentration of carbohydrate, protein, nitorgenous compound, lipid, and minerals that can be utilized as a food source by aquatic organisms [23]. Also, it comprises various essential nutrient elements namely nitrogen, phosphorous, calcium, magnesium, and potassium in POME that can be reused or returned to the plantation in the form of fertilizer [24]. Besides all the nutrients, POME usually contains heavy metals such as zinc (Zn) and iron (Fe), which are toxic and non-biodegradable which can affect aquatic living organisms and cause adverse effects to humans health [25]. Table 3 shows the element content in raw POME.

| Element       | Concentration (mg/L) | Element       | Concentration (mg/L) |
|---------------|----------------------|---------------|----------------------|
| Potassium     | 3713.99              | Strontium     | 3.14                 |
| Magnesium     | 467.58               | Cobalt        | 1.80                 |
| Calcium       | 275.16               | Copper        | 1.82                 |
| Phosphorous   | 180                  | Iron          | 1.42                 |
| Sodium        | 50.21                | Gallium       | 1.37                 |
| Bismuth       | 7.61                 | Manganese     | 1.92                 |
| Aluminum      | 3.31                 | Zinc          | 1.60                 |
| Rubidium      | 3.87                 | Barium        | 1.63                 |
2.3. Regulation control of effluent discharge

Table 4 shows the parameters limit for watercourse discharge of liquid effluent from three world’s largest production of palm oil industry. It is clear that regulation on the limit for watercourse discharge of effluent is necessary in order to protect the watercourse and coastal ecosystems. Generally, the government of a country will appoint an organization to monitor the quality of effluent and put a punishment to those who do not comply with the regulation. Even though it has been under a very strict regulation implemented by the government for each palm oil exporter country, in many cases, the palm oil factories are failed to comply with the standard discharge limit. This issue can be related to the difference in POME properties and the overflow of effluent during heavy rain to a nearby river [27].

Table 4. Parameters limit for watercourse discharge of effluent from oil palm industry in Malaysia, Indonesia and Thailand [28,29,30].

| Parameters           | Units       | Limit Discharge |
|----------------------|-------------|-----------------|
|                      |             | Malaysia | Indonesia | Thailand |
| BOD                  | mg/L        | 100      | 250       | 100      |
| COD                  | mg/L        | *        | 500       | 1000     |
| Total Solid          | mg/L        | *        | N/A       | N/A      |
| Suspended Solid      | mg/L        | 400      | 300       | 150      |
| Oil and Grease       | mg/L        | 50       | 30        | 25       |
| Ammoniacal nitrogen  | mg/L        | 150      | 20        | N/A      |
| Total Nitrogen       | mg/L        | 200      | N/A       | 50       |
| pH                   | -           | 5 - 9    | 6 – 9     | 5 - 9    |
| Temperature          | °C          | 45       | N/A       | 40       |

*Note: * No discharge standard after 1984, N/A Not Available

2.4. Current POME treatment: ponding system

Ponding system is the widely used treatment method for POME in Malaysia with more than 85% of mills have adopted the treatment system since it is inexpensive, has a low operational maintenance, has a simplicity and ease of handling [31]. Basically, biological treatment processes of the ponding system can be divided into anaerobic, facultative, aerobic and aerated [32]. The energy demand consumption for ponding systems is low due to the absence of mechanical mixing and rarely operation control or monitoring. According to Zainal et al. [31], ponding system has been found to show a productively reduced in the concentration of pollutants up to 100-1725 mg/L for COD, 100-610 mg/L for BOD and 100-200 mg/L for ammoniacal nitrogen.

![Diagram of POME waste water treatment plant](image)

**Figure 2.** Layout plan for POME waste water treatment plant.

Formation of scum and the accumulation of solid sludge at the bottom of the system pond is considering one shortcoming of the treatment. When scum and sludge mix together for a long time it will lower the effectiveness of the system by decreasing the volumetric proportion and required long hydraulic retention time for degradation. Besides, the microbial in charge for waste breakdown are
kept in suspension and bubbles rise to surface of water [33]. Other disadvantages of ponds system are requiring large land area, control and monitoring systems are difficult because of the pond size. Despite of these weaknesses, this system offers an easy technology, lower construction and maintenance cost, is easy to manage and operate as the technology required is relatively uncomplicated, therefore skilled worker is not required. The layout plan for POME waste water treatment plant are summarized in figure 2.

2.4.1 Anaerobic pond. Anaerobic digestion is one of the most useful biological treatments for POME treatment which gives very significant BOD reduction up to 90%, COD and O&G. However, it has less tolerance to nitrogen, phosphorus and pathogen number. In anaerobic pond treatment, microorganism is used to breakdown all organic matters (carbohydrates, protein, oil, and fat) in the effluent without the presence of oxygen or other oxidizing chemicals to produce methane and carbon dioxide. Anaerobic ponds are usually 7-19 foot depth or as deep as possible without reaching groundwater to minimize the presence of oxygen and maximizing heat retention. At such depths, it will result in lowering oxygen transfer and improving the performance of the microorganism to digest the organic matter. There are three steps of biological conversion of organic matter: (i) hydrolysis (organic polymers such as polysaccharides, protein, and lipid are broken down to monomer by hydrolytic bacteria), (ii) acidogenesis (fermentation forming simpler organic compound volatile fatty acid) and (iii) methanogenesis (volatile fatty acid into methane and carbon dioxide) [34]. Anaerobic processes also produce renewable energy source in the form of biogas methane, and other by–product such as hydrogen sulfide, ammonia, carbon dioxide, a variety of amine, and volatile acid compound [35]. The illustration of the anaerobic pond is shown in figure 3.

The advantage of anaerobic ponds impacts on the high removal of organic load, the tolerance to high TSS and O&G level effluent, low operating input, production of valuable by-product methane gas, production of less sludge than other technologies [17]. It has been estimated that up to 28 m³ of biogas (70% methane, 30% carbon dioxide and a trace amount of hydrogen sulfide) was produced for 1 m³ of POME which equivalent to more than 168 kWh of electricity generating capacity (1 m³ = 6kWh) [45]. Besides the entire aforementioned advantages anaerobic pond also has weaknesses: it has difficulty to collect and utilize the methane gas since the pond is normally designed in the open-air system [18]. Other disadvantages are effluent needs further treatment, long retention time, low process stability, and low start-up period [17]. Since anaerobic pond also produces hydrogen sulphide, several of amine and volatile acid compound that can cause an obnoxious and offensive odor. At the anaerobic zone, methane gas has also been produced which can cause 21 times higher heat-trapping ability of greenhouse gas than carbon dioxide [36].

![Figure 3. Illustration of Anaerobic Pond](https://example.com/figure3.png)
2.4.2 Facultative pond. In the facultative ponding system, it has three distinct layer combinations of aerobic, facultative and anaerobic layers. At the first layer (top zone), algae use carbon dioxide, ammonia, phosphates and sunlight for the encouragement of photosynthesis and metabolic processes, thus ultimately releasing oxygen. Meanwhile, at the second layer (middle zone) the condition is rather in between aerobic and anaerobic operation. With the absence of minimal volume of oxygen, the facultative bacteria tend to grow more rapidly and oxidise the organics in middle zone. At third layer (bottom zone) with the total absence of oxygen, the anaerobic bacteria come in contact with the settled solids and organic matter in the wastewater and consume it as food which will then release hydrogen sulphide, carbon dioxide and methane [36].

Figure 4 shows the illustration of facultative pond. Facultative organisms can perform with or without dissolved oxygen at range 8-9 foot depth. The advantages of facultative ponds are moderately effective in removing organic load, the design of the pond is simple and cheap to construct, easy to operate, low odor when operated properly, no energy required, and little operational input needed [37]. Several disadvantages of facultative ponds are settled sludges and inert materials require periodic removal, produce unpleasant odors when aerobic blanket disappears or when effluent overloaded, no significant nutrient or pathogen removal and may produce some methane.

![Figure 4. Illustration of Facultative Pond](image)

2.4.3 Aerobic/algae pond. Aerobic ponds are also known as algae ponds where oxygen is present throughout the entire depth of the pond all the time in order to promote the photosynthesis process of the algae or microorganism. Photosynthesis is a biological process that occur naturally in which algae use carbon dioxide along with the presence of sunlight to produce oxygen and carbohydrates. In wastewater treatment ponds, oxygen released from the photosynthesis process is used by the bacteria to stabilize the suspended organic material in wastewater. Bacteria use the oxygen to break down organic matter into simpler compounds, and releasing carbon dioxide for the use of algae. Breaking down organic material will reduce BOD level. At night, the photosynthesis activity by the algal cell will reduce and the algae use dissolved oxygen and discharge CO₂ in the process of respiration that lower the pH and cause to the longer hydraulic retention time.

To ensure the light able to penetrate fully around the pond and support the photosynthesis process so the deep of the ponds usually 6-7 feet. Therefore, sunlight is an important factor in aerobic pond. Aerobic bacteria and algae will stabilize the organic wastes for affluent and emit dissolved oxygen as a by-product of photosynthesis. The illustration of aerobic pond is shown in figure 5.
The advantages of aerobic ponds are the resistance to organic and hydraulic shock loads, no continuous sludge handling, fewer mechanical problems, low operational, and energy cost. Meanwhile, the disadvantages of the aerobic ponds are it requires a large land area, climatic condition, vegetation (algae), labour intensive, and costly sludge removal [38].

\[ \text{Aerobes} \rightarrow \text{O}_2 + \text{NH}_3 + \text{PO}_4^- \rightarrow \text{CO}_2 + \text{NH}_3 + \text{PO}_4^- \]

\[ \text{Bacteria} \rightarrow \text{Sludge} \]

\[ \text{Algae} \rightarrow \text{Dead Cell} \]

\[ \text{SUNLIGHT} \rightarrow \text{Algae Biomass} \]

\[ \text{NH}_3, \text{PO}_4^- \rightarrow \text{Aerobic Bacteria} \]

\[ \text{6 – 7 feet} \]

**Figure 5.** Illustration of Aerobic Pond [40].

### 2.4.4 Aerated pond

Aeration pond (6-20 feet depth) is a process that adding oxygen provided by aerator to increase the dissolved oxygen levels in the pond thus maximize the aerobic microorganism activity in the consumption of pollutant in a reasonable time. The second function of the aerated pond was to keep microbial biomass in suspension with the continuously stir thus avoiding a build-up of sludge and also ensure that the entire pond in contact with the oxygen. Mixing will also exhaust the carbon dioxide from the system, as a result, the store of carbon dioxide is depleted and algal growth becomes limited. The microbes biodegrade on the organic pollutants and create an accumulate of bacteria floc on the bottom of the tank or lagoon which can easily settle out which called as activated sludge.

The advantages of aerobic ponds are capable to adapt high organic and hydraulic loads, very efficient for BOD and pathogens reduction, less production of offensive odours with the right design and maintenance, less land required, and the treated water can be recycled and reused when a secondary maturation/settling pond was conducted followed with the aerated pond. Meanwhile, the disadvantages are it requires high energy consumption to turn on the aerator system, high capital and operating costs depending on the price of land and electricity, skilled operation workers for operation and maintenance, professional design and construction management, sludge and possibly effluent might require further treatment [39].

### 3. Materials and methods

The water quality assessment was conducted to observe and collect the background information of the POME in ponding system and how the total average rainfall was affected by its parameter. The POME from cooling pond was chosen for the monitoring study that was obtained from the palm oil mill located at Trolak, Perak, Malaysia. Basically, a total of 12 monthly samplings had been collected every month started from January to December 2019. Since the fresh POME had a temperature ranging
between 75 - 90° C, it was allowed to cool around 40 - 45°C before being collected into polyethylene bottles. The sample was kept at low temperature 4°C in airtight bottle to prevent biodegradation due to the microbial activity. The physicochemical parameter (BOD and SS) of POME were measured in situ by using recommended method suggested by APHA Standard Method Examination of Water and Wastewater. The BOD and SS parameter was determined by using APHA method 5210 and 2540, respectively.

4. Results and discussion

4.1. Water quality monitoring

Figure 6 showed the assessment of the water quality trends of POME at cooling pond though over the year of 2019. The use of the monitoring was to determine the parameters trend of the POME and to study the relationships between climate changes and the parameters of the POME. According to the data released by the Malaysian Meteorological Department, the rainfall pattern in Perak showed the lesser rainfall distribution from January to February, June to July and December than the rest of the month at below 120 mm of average rainfall. While April and August to November recorded highest average rainfall above 300 mm.

![Figure 6. Monitoring studies of raw POME.](image)

From figure 6 it clearly showed that the rainfall pattern and trends significantly affected the concentration of BOD and SS in the POME. As we can see, in February which received the lowest amount of rainfall with monthly average rainfall approximately 85.96 mm, gave the highest reading of BOD at 36,200 mg/L and the lowest reading of SS at 10,522 mg/L. However, at highest monthly average rainfall (November) shows the lowest BOD and highest SS at 23,100 mg/L and 24,302 mg/L, respectively. The turbidity and TSS reading might be increased at heavy rainfall season due to pond banks erosion, and an increase in flow rates during heavy rainfall would keep suspended solid instead of settle at the bottom of pond [43]. Meanwhile, the decrease of BOD concentration in rainfall season was caused by the lower content of organic carbon in suspended solids and a lower biodegradability of organic carbon [44]. Thus, the result revealed that the relationship of total rainfall distribution would change the trends of BOD and SS concentration.
4.2. Factors affecting ponding treatment

There are several conditions that might affect ponding treatment biological activity, primarily climatic condition, vegetation and seasonal changes.

4.2.1 Climatic condition. Sunlight, temperature and wind were the three primary climatic conditions that might affect the biological activity of the pond treatment. First, sunlight was the key factor for photosynthesis performance and influenced the oxygen production in a pond. The depth of pond was also important to determine the light penetrates through the pond which encouraged the algae to grow, and the production of oxygen. Second, temperature also affected the microorganisms growth rate and activity. As temperatures increased during summer, the bacteria and algae activity also increased. While the microorganisms activity was the lowest during the winter. At extremely cold temperature, ice and snow would cover the surface pond that limits the sunlight penetration, as well as in raining season. Third, the wind produced natural mixing to the pond which transfers the oxygen throughout the pond and its surface. The effectiveness of the biological treatment in the pond would be enhanced when sufficient mixing occurred between oxygen, algae, bacteria and organic matter. In addition, the mixing operator was also to control the growing of vegetation on the pond surface [40].

4.2.2 Vegetation. Overabundant duckweed (lempaccae) would create a floating mat on the surface of the pond which restricting UV penetration that inhibited algae growth. This would lowering the dissolved oxygen levels and BOD treatment since the duckweed prevented the photosynthesis process of algae in the pond. For a good reason, a little quantity of duckweed could be advantageous to control algae thrive and very effective at adsorbing nutrients. However, it just took it into its cell wall without rib the nutrient and would realize the nutrient back into the water once it died [41].

There were many different forms of algae growing in wastewater treatment ponds, they were commonly green and blue-green algae. Green algae would be predominating when pond conditions and treatment yield the best result which gave the green color to the ponds. While blue-green algae were filamentous that showed bad pond treatment condition and often formed unsightly and odorous mats. The pond content blue–green algae will have high organic loading, low dissolved oxygen (DO), warm water temperature conditions, and low in nutrients [42].

4.2.3 Seasonal changes. Treatment efficiency decrease in the raining season were reduced in sunlight penetrated period and limits the quantity of photosynthesis process, which reduced the dissolved oxygen in the pond. Raining season would also decline the bacterial activity than decreasing the treatment efficiency and the entire pond might go anaerobic. While in the summer period the entire pond would obtain maximum oxygen levels for algae photosynthesis activity. Warm water temperatures could increase bacteria action to produce the best environment for efficient ponding treatment [40].

5. Conclusions and recommendations

As the palm oil industry continues to expand to fulfil the global demand, the generation of POME is also expected to increase significantly. However, there are several pose of a challenges and issue related to the POME, in term to ensure that the final discharge effluent obeys with the standards limit set up by the Department of Environment Malaysia. Undoubtedly, the conventional ponding system was still the most favoured POME treatment method used in most palm oil mill in Malaysia, although it required a high retention time and large treatment areas. This was due to the capability of ponding system to reduce the BOD and degrade the contaminant at low operational cost and maintenance for enormous amount of POME under various climate change scenarios. However, further studies should be conducted to improve the rate of degradation to reducing the hydraulic retention time, by introducing new methods or enhancing the existing treatment method. Beside that, anaerobic digestion of ponding system has generated enormous amount of methane gas that can cause emission of greenhouse gases (GHG) which contribute to global warming. Therefore, installing the biogas capture
system in pond is necessary, and in the future, the methane emission would have the potential to be turned into renewable energy. From the monitoring of water quality, the analysis of BOD and SS parameter of POME showed that, in general the average monthly rainfall significantly influenced the concentration of the parameters. The trends found in this study indicated that the reading of BOD was the highest and lower in SS at dry season, and vice versa in rainy season.

Acknowledgement
The authors would like to express their sincere gratitude to Department of Chemistry, Faculty of Science and Mathematics, Universiti Pendidikan Sultan Idris for providing the instrumentation services for this research.

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