Chapter 2

Palm Oil Mill Effluent as an Environmental Pollutant

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Abstract

In recent decades, Malaysia has been known as one of the world's leading producers and exporters of palm oil products. Every year, the number of palm oil mills increases rapidly, thus increasing the capacity of fresh fruit bunch waste or effluent discharge. Based on the data from the Malaysian Palm Oil Board in 2012, Malaysia produced 99.85 million tons of fresh fruit bunch (FFB) per year. However, about 5–5.7 tons of water was required in order to sterilize the palm fruit bunches and clarify the extracted oil to produce 1 ton of crude palm oil resulting in 50% of the water turning into palm oil mill effluent (POME). POME is one of the major environmental pollutants in Malaysia. The characteristics of POME and its behavior, if discharged directly, in water are described in this chapter. The suspended solid and nutrient content in POME could be able to support the growth of algae. This chapter aims to demonstrate that POME could be used as a main source for algae production, and this effluent is one of the main environmental problems in the tropical region especially in Malaysia.

Keywords: POME, Malaysia, wastewater, environmental pollution,industry

1. Introduction

These days, palm oil enterprise is developing quickly and turning into a noteworthy agriculture-based industry in Malaysia. The quantity of palm oil mills has elevated relatively, at beginning with 10 mills in 1960 moved to 410 operated mills in 2008. At least 44 million tons of POME was produced and are increasing every year in Malaysia [1], particularly because of the initiative of the government to promote palm oil industry. While the palm oil industry has been recognized strongly for its contribution toward economic growth and rapid development, it has also contributed to environmental pollution due to the production of large quantities of by-products during the process of oil extraction [2, 3]. Furthermore, it is necessary to properly address the POME treatment so as not to contribute to human health hazards and environmental pollution.

POME is the wastewater produced by processing oil palm and comprises of different suspended materials. POME is 100 times more polluted than the municipal sewage which has a high biochemical oxygen demand (BOD) and chemical oxygen demand (COD). The effluent also contains higher concentration of organic nitrogen, phosphorus and different supplement substance [4]. POME is a non-harmful waste; however, it will pose environmental issue because of vast oxygen draining capacity to oceanic framework because of natural and supplement substance. It is also known to be a good source of nutrients [5]. The waste products generated during palm oil processing consist of oil palm trunks (OPT), oil palm fronds (OPF), empty fruit bunches (EFB), palm pressed fibers (PPF) and palm kernel shells, less fibrous material such as palm kernel cake and liquid discharge POME [2]. The wastes are in the form of high organic matter concentration such as cellulosic wastes with a mixture of carbohydrates and oils. The discharge of untreated POME creates adverse impact to the environment [6].

Nowadays, biological process is the most common practice way for the treatment of POME based on anaerobic and aerobic ponding system [2]. While the emerging technologies for the treatment of POME, the notion of nurturing POME and its derivatives as valuable resources should not be dismissed. Furthermore, it is necessary to properly address the POME treatment so as not to contribute to human health hazards and environmental pollution. At the point when contrasted with those routine wastewater treatment processes which introduce activated sludge and living floc to degrade natural carbonaceous issue to CO_2, and microalgae may acclimatize natural toxins into cell constituents, for example, lipid and carbohydrate, therefore attaining pollutant decrease in a more ecological friendly way [7]. Actually, microalgae have turned into the consideration for both wastewater treatment and biomass production as early as 1950s [8]. Small scale and economically viable technologies that combine wastewater treatment and energy production can treat the industrial effluents and enhance the availability of the energy simultaneously [9]. The feasible way that is more attentions in the present time is the use of microalgae, which is known to have the potential to treat wastewater [10] such as removal of CO_2 and NOx [11] and high capacity of nutrient uptake [12]. The idea of using microalgae in wastewater treatment has been investigated since 1950s by Oswald and Gotaas [8]. There are several important aspects to be considered during the current study. POME is the major source of water pollutant in Malaysia [13]. For example, in a conventional palm oil mill, 600–700 kg of POME is generated for every 1000 kg of processed fresh fruit bunches (FFB) [14]. By utilizing the ingredients present in POME, this study will play a major role to solve the pollution problem resulting from the POME as it will pollute the environment if it is improperly discharged into the environment.

2. Palm oil mill effluent

In particular, POME is a basic expression referring to the effluent from the last phases of palm oil manufacture in the mill. It incorporates different fluids, dirt, leftover oil and suspended solids. POME in its untreated shape is a high quality waste, relying upon the operation of the procedure. POME is generated mainly from oil extraction, washing and cleaning processes in the mill, and these contain cellulosic material, fat, oil and grease, and so on [15]. POME also contains substantial quantities of solids; both suspended solids and total dissolved solids in the range of 18,000 and 40,500 mg/L, respectively.

Oil palm is the most productive oil producing plant in the world, with 1 ha of oil palm producing between 10 and 35 tons of fresh fruit bunch (FFB) per year [15]. During processing of oil palm, more than 70% by weight of the fresh fruit brunch was left over as waste [16]. Usually, the harvested part is the fruit whereby oil is obtained from the fleshy mesocarp of the fruit. Despite the importance of the edible oil and fats extracted from the palm fruits, the POME contains residual oil which affects the environment cannot be ignored. Treatment and disposal of oily wastewater such as POME is presently one of the serious environmental problems. Palm oil mill wastes have existed for years but their effects on environment are at present more noticeable [15]. The oily waste has to be removed to prevent problems which are considered as hazardous pollutants particularly in the aquatic environments because they are highly toxic to the aquatic organisms. Discharging the effluents or by-products on the lands or release to the river may lead to pollution and might deteriorate the surrounding environment. In order to conserve the environment, an efficient management system in the treatment of these by-products is needed [17]. Treatment of POME is essential to avoid environmental pollution [18].

POME wastes are the fiber free non-oil components obtained from the clarification zone of an oil mills. The significant contamination comes out of the fresh fruit brunch (FFB). In fact, every ton of FFB is composed of 230–250 kg of empty fruit bunches (EFB), 130–150 kg of fibers, 60–65 kg of shell and 55–60 kg of kernels and 160–200 kg of unrefined oil [19]. POME contains high amounts of oil and grease (4000 mg/L) and COD (50,000 mg/L). Although the effluent is nontoxic, it has a very high concentration of biochemical oxygen demand (BOD) (i.e., 25,000 mg/L) which becomes a serious threat to aquatic life when discharged in relatively large quantities into watercourses. The high amount of total solids (40,500 mg/L) contributes to the large amount of nutrients available in the wastewater, hence possible algae bloom.

Most palm oil mills in Malaysia have adopted the ponding system for the treatment of POME [20]. In general, there are four types of treatment systems adopted by the palm oil industry, which are as follows:

a. Waste stabilization ponds,

b. Activated sludge system,

c. Closed anaerobic digester and

d. Land application system.

The most proper secondary treatment for POME is natural assimilation with the blend of anaerobic and aerobic ponds. Right now, the management of POME has developed from treatment of waste for transfer to gainful use of assets. POME contains generous amounts of significant plant supplement that shift as indicated by the level of treatment to which it is subjected. The potential utilization of recovery of water and natural issues from POME has been applied for different applications [21]. Commercial trials and applications of these technologies are currently underway, especially conversion of the solid residual materials into saleable value-added products.

2.1. Malaysian palm oil industry

In 2011, Malaysia was the second biggest oil palm producer in the world, with an aggregate of 16.6 million tons, a sum lesser than 1% from the total world's supply behind Indonesia. Since the oil palm industry is tremendous, with 67% of agricultural land secured with oil palm tree, biomass from oil palm contributes the most. As of now, 85.5% of the biomass residues are originating from the oil palm industry. Palm oil has a very good potential in producing alternative energy due to its calorific content. With 50% efficiency, biomass from oil palm can generate 8 Mton of energy and can save RM 7.5 billion per year of crude oil [14, 19]. More than 85% of palm oil mills in Malaysia have adopted ponding system for treating POME [20], while the rest have opted for open digesting tank [22]. These methods are regarded as conventional POME treatment method, whereby longer retention time and large treatment areas are required [23]. The effluent that comes out from palm oil mill is hazardous to the ecosystem due to its high-volume composition and nutrient. The discharge can lead to land and aquatic pollution if it is left untreated [24].

In view of the measurement estimation of aggregate unrefined palm oil generation in May 2001, the production of 985,063 ton of crude palm oil means, a total of 1,477,595 m^3 of water is being used, and likewise, 738,797 m^3 POME is discharged for a month. Without appropriate treatment, this wastewater will contaminate the encompassing surrounding. The present treatment technology of POME normally comprises of natural aerobic and anaerobic digestion. Biologically treated effluent is disposed via land provision system, hence providing vital supplements for growing plants. This system might be a decent decision for the disposal of treated effluent. However, acknowledging those rates of daily wastewater generation, for instance, around 26 m^3/d for an average palm oil mill with an operating limit of 35 t/d FFB, it is doubtful that the surrounding plantations receiving it might effectively absorb all the treated effluent [25].

2.2. Palm oil management

Around 44 million m^3 of POME were produced in year 2013 to yield 19.66 million tons of total crude palm oil [14]. Around 85% of palm oil mills have treated raw POME using biological treatment [26]. The biological treatment of POME is a series of pond systems, including anaerobic, facultative and aerobic pond systems [19, 27]. However, the final treatment by aerobic pond system is struggling to achieve the discharge standards because of inefficient operational design [3]. The final effluent of the treated POME must comply with the discharge standards set by the Department of Environment (DOE), Malaysia. There is a requirement for a sound and effective management system in the treatment of these by-products in such a way that will assist to protect the environment and check the deterioration of air and river water quality. Treatment of POME is vital to avoid environmental contamination [28].

2.3. Current state of POME treatment

Indonesia and Malaysia are the two biggest oil palm manufacturing nations and is rich in various endemic and forest dwelling species [29]. Malaysia has a tropical atmosphere and is prosperous with regular assets. Oil palm as of now involves the biggest real acreage of cultivated land in Malaysia [30, 31]. The total oil palm acreage from 1970 to 2000 has expanded from 320 to 3338 ha. In the year 2003, there were more than 3.79 million ha of land under palm oil cultivation, occupying more than 33% of the total developed area and 11% of the total land area of Malaysia [32]. Palm oil, edible oil, is derived from the meaty mesocarp of the fruit of oil palm (*Elaeis guineensis*). One hectare of oil palm produces 10–35 tons of fresh fruit bunches (FFB) per year [2, 33]. Malaysia produces about 41% of the world's supply of palm oil as shown in **Figure 1**. Malaysia also accounts for the highest percentage of global vegetable oils and fats trade in the year 2005 [34].

The oil palm has the expectancy of over 200 years, whereas the economic life is about 20–25 years. The nursery period is 11–15 months for plants, and first harvest is done after 32–38 months of planting. It takes 5–10 years for palm oil plant to reach the highest yield. The yield is approximately 45–56% of FFB, and the fleshy mesocarp of the fruit is used to get oil. The yield of oil from the kernel is about 40–50% [35]. Both mesocarp and kernel of fruit produce about 17 t ha^{-1} yr^{-1} of oil [6]. Starting with 5.8 ton of FFB about 1 ton of crude palm oil (CPO) is produced [2]. The world palm oil production is shown in **Table 1**.

While the oil palm industry has been recognized for its contribution toward economic growth and rapid development, it has also contributed to environmental pollution due to the production of huge quantities of by-products from the oil extraction process [2].

2.4. Characteristic of POME and utilization by microalgae

POME contains high content of degradable organic matter, which is due in part to the presence of uncovered palm oil [36]. The discharge of improperly treated POME creates adverse impact to the environment (**Table 2**). However, the substances in POME are able to support the growth of microalgae. Microalgae naturally exist in many palm oil mill processes, phenomena known as "algae bloom," hence declining the water quality. Because POME consists of large amount of organic compounds and inorganic compounds which is hazardous to environmental health, microalgae have been suggested as a potential candidate to remove these pollutants and able to breakdown the organic compounds present in it [37, 38].

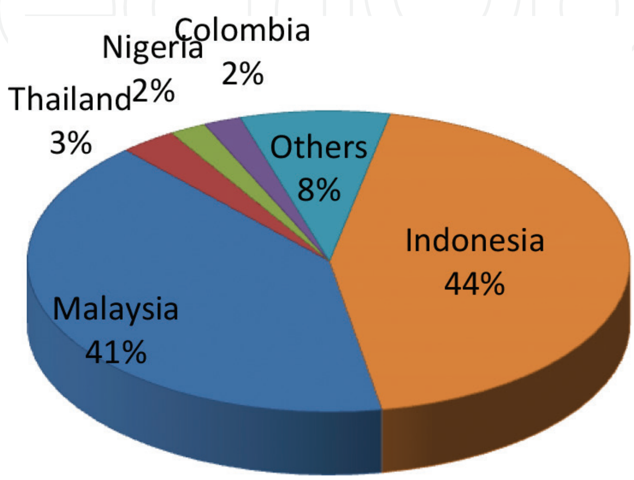

Figure 1. Palm oil production in 2007 [6].

Country	Share (%)	Amount (tons)
Indonesia	44	19,000
Malaysia	41	17,350
Thailand	3	1123
Nigeria	2	850
Colombia	2	832
Others	8	832

Table 1. World palm oil production [2].

Parameters	Concentration (mg/L)	Standard limit (mg/L)
pH	4.7	5–9
Oil and grease	4000	50
BOD	25,000	100
COD	50,000	—
Total solids	40,500	—
Suspended solids	18,000	400
Total nitrogen	750	150

Table 2. Characteristics of POME and its respective standard discharge limit by the Malaysian Department of Environment [19, 20].

Alternatively, culturing microalgae in wastewater offers an economy, which is alternative to the traditional types of wastewater treatment [39, 40]. In the meantime, microalgae can apply the nitrogen and phosphorus compound in wastewater to produce microalgae biomass for various kinds of lipid generation, which can serve as a substrate for biofuel production [38, 41].

POME is a colloidal suspension, starting from the blend of sterilizer condensate, separator sludge and hydrocyclone wastewater in a proportion of 9:15:1, respectively [1]. In total, about 2.5–3.0 tons of POME for huge amounts of produced crude palm oil is obtained in the extraction procedure [42]. Fresh POME is a thick brownish colloidal blend of water, oil and fine-suspended solids. It is hot (80–900°C) and has a high BOD, which is 100 times as contaminating as domestic sewage [1]. The effluent is not hazardous, as no chemicals are added to the extraction procedure [43], and also acidic with a pH around 4.5 as it contains organic acids in complex forms that are suitable to be used as carbon sources [44]. Palm oil mill effluent is a high-strength pollutant with low pH due to the organic and free fatty acids arising from partial degradation of palm fruits before processing. The characteristics of POME depend on the quality of the raw material and the production processes [24]. It typically contains large amounts of total solids (40,500–75,000 mg/L) and oil and grease (2000–8300 mg/L). Its total nitrogen in the range of 400–800 mg/L and suspended solids contents in the range

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of 18,000–47,000 mg/L. POME also has very high BOD and COD contents which are in the range 25,000–54,000 mg/L and 50,000–100,000 mg/L, respectively [45]. POME while fresh is hot acidic and pH range between 4 and 5, brownish colloidal suspension containing high concentrations of natural matter, high quantities of total solids (40,500 mg/L), oil and grease (4000 mg/L) COD (50,000 mg/L) and BOD (25,000 mg/L) [15]. However, it also contains appreciable amounts of N, P, K, Mg and Ca which are the vital nutrient elements for plant growth [46]. The characteristic of POME based on Malaysian Palm Oil Board is shown in **Table 3**.

According to Kamyab et al. [46], the raw or partially treated POME has an extremely high content of degradable organic matter. However, it has nontoxic nature and has fertilizing properties, POME can be used as fertilizer or animal feed substitute, in terms of providing sufficient mineral requirements. The Malaysian government provides an effort to reduce the effluent of palm oil through licensing system, which mainly consists of effluent standards and effluent charges. According to POME characteristic and standard discharge limit in Environmental Quality Act (EQA) 1974, the palm oil industry faces the challenge of balancing the environmental protection, its economic viability and sustainable development. The year 1978 witnessed the enactment of the Environmental Quality Regulations detailing POME discharge standards. **Table 4** shows the palm oil mill effluent discharge standard that must be followed.

Normally, the characteristics of POME may vary considerably for different batches, days and factories, depending on the processing techniques and the age or type of fruit as well as the discharge limit of the factory, climate and condition of the palm oil processing [19]. Occasional oil palm cropping and activities of the palm oil will also impact those quality and quantity of the discharged POME, thus influence the ecological treatment procedure of POME [27]. Hence, the variation of the characteristics of POME, in terms of its quality and quantity, is the main reason that causes selection in the treatment of POME in the palm oil industries [1, 47].

Parameter	Mean	Range
pH	4.2	3.4–5.2
Biological oxygen demand	25,000	10,250–43,750
Chemical oxygen demand	51,000	15,000–100,000
Total solids	40,000	11,500–79,000
Suspended solids	18,000	5000–54,000
Volatile solids	34,000	9000–72,000
Oil and grease	6000	130–18,000
Ammoniacal nitrogen	35	4–80
Total nitrogen	750	180–1400

*Units in mg/L except pH.

Table 3. Characteristics of POME [14].

Palm oil mill effluent discharge standards	1/7/78–30/6/79	1/7/79–30/6/80	1/7/80–30/6/81	1/7/81–30/6/82	1/7/82–31/12/83	1/1/84–there after
pH	5–9	5–9	5–9	5–9	5–9	5–9
BOD	5000	2000	1000	500	250	100
COD	10,000	4000	2000	1000	—	—
Total solids	4000	2500	2000	1500	—	—
Suspended solids	1200	800	600	400	400	400
Oil and grease	150	100	75	50	50	50
Ammoniacal nitrogen	25	15	15	10	150	100
Total nitrogen	200	100	75	50	—	—
Temperature °C	45	45	45	45	45	45

*Units in mg/L except pH and temperature.

Table 4. Environmental quality [14, 42].

2.5. Wastewater treatment technology

The wastewater treatment technologies are expensive, dependent on skilled personnel and hard to carry out, as the volume of contaminated wastewater is huge [38]. Furthermore, the common conventional treatment is unable to meet the regulations set by the Department of Environment (DOE) with the level of BOD at 100 mg/L. According to Ahmad et al. [19], large quantities of water are used during the extraction of crude palm oil from the fresh fruit bunch, and about 50% of the water results in POME. The disposal of this very contaminating effluent is turning into a noteworthy issue assuming that it may be not continuously treated appropriately as well as a severe standard boundary obligatory set by the Malaysian Department of Environment for the discharge of effluent. A POME treatment system based on membrane technology shows high potential for decreasing the ecological issue, and also, this alternative treatment system offers water reusing [19].

The utilization of wastewater for the microalgal growth is considered beneficial for limiting the utilization of freshwater, dropping the cost of supplement option, expelling nitrogen and phosphorus from wastewater and generating microalgal biomass as bioresources for biofuel or value-added by-products. Three primary sources of wastewater are municipal (domestic), agricultural and industrial wastewater which included a variety of elements. Some elements in the wastewater, such as nitrogen and phosphorus, are valuable components for microalgal cultures [48].

2.6. POME as nutrients source to culture microalgae

A life cycle assessment on microalgae cultivation has underlined that 50% of energy use and greenhouse gas emissions are associated with fertilizer (nutrients) [49]. In general, culturing of microalgae on a large scale required high nitrogen and other related chemical fertilizers, which driven the process toward non-environmental friendly. On the other hand, culturing microalgae can actually play an important role as a self-purification process of natural wastewaters [50].

Utilizing POME as supplements source to culture microalgae is not an another scenario in Malaysia. Most palm oil millers favor the culture of microalgae as a tertiary treatment before POME is released because of practically low cost and high impact. Consequently, vast majority of the nutrients such as nitrate and ortho-phosphates that are not detached during anaerobic digestion will be additionally treated in a microalgae pond. Thus, the cultured microalgae will be used as a food nutrition for live feed culture [50] Meanwhile, nitrogen source (usually

Source of POME/ concentration	Microalgae	Growth condition	References
POME collected from pond with no dilution	*Chlorella pyrenoidosa*	3 L PBR system Temperature: 24–26°C Mixing 60 rpm Lighting 8 h:16 h L:D pH 6.5–7.5 Light intensity of 150 μmol m^{-2} s^{-1}	[56]
Fresh POME with dilution 50% + 1 g/L urea	*Chlorella* sp.	1 L glass flask disk Light intensity 3000 lx pH 6.8–7.2, Temperature 28°C Mixing using aeration aquarium air pump	[4]
POME from anaerobic pond with 40% dilution	*Spirulina platensis*	1 L glass flask disk Mixing using aeration aquarium air pump pH 9–10.5 Light intensity, 4000–6000 lx	[57]
POME collected from pond with concentration 250 mg COD/L	*Chlorella sorokiniana*	Room temperature Light intensity-continuous illumination at intensity of ±15 μmol m^{-2} s^{-1}	[58]
POME collected from pond with concentration 250 mg COD/L	*Chlorella pyrenoidosa*	5 L HPBR reactor with turbine impeller Temperature, 30°C Light intensity, illuminated by four 32 W white fluorescence light continuous lighting (24 h) (Philip, Germany) C:N, 100:6 OLR, 36 kg COD m^{-3} d^{-1}	[46]
POME collected from pond with concentration 250 mg COD/L	*Chlamydomonas incerta*	250 mL Erlenmeyer flask Temperature, 30°C Light intensity, 15 μmol m^{-2} s^{-1} C:N, 100:7 OLR, 36 kg COD m^{-3} d^{-1}	[38]

Source of POME/ concentration	Microalgae	Growth condition	References
Fresh POME with dilution of 500 mL of POME in 400 mL deionized water	*Chlorella* sp.	1 L conical flask Pressure regulators bring down the pressure of both CO_2 and compressed air to 2 bars before entering their flow meters. The sparging tube of a flask culture was placed at the bottom of the flask Light intensity, 10,000 lx CO_2 concentration (% v/v), 16% Sparging rate (vvm), 0.8 vvm	[59]
Fresh POME with dilution of 1%	*Arthrospira platensis*	10 L of culture media in 20 L tank Outdoor	[60]

Table 5. Growth conditions for microalgae using POME.

appears in nitrate form) plays an important role in promoting microalgae growth. In order to grow microalgae effectively, the basic nitrate concentration required is in the range of 200–400 mg/L [51]. Others minerals such as Fe, Zn, P, Mg, Ca and K that are required for microalgae growth are also present in POME. Thus, POME emerged to be an alternative option as a chemical remediation to grow microalgae for biomass production and simultaneously act as a part of wastewater treatment process [50].

These days, there is an incredible and nonstop increment in industrialization, foundation and urban expansion in Asia, which has added to the critical wastes demand and water deficiency because of water contamination [52]. Industry in particular agro-based industry is one of the significant divisions releasing extensive amount of wastewater yearly influencing the other water sources and human life. The palm oil industry in Malaysia is generating the biggest amount of natural contamination loads into rivers [30, 33]. POME is a highly polluted waste having unpleasant odor. There is a greater need to find alternative way to utilize these organic pollutants for the good benefit of both human beings and the environment [21]. Microalgae cultivation in POME offers an alternative to conventional forms of tertiary wastewater treatments and spontaneously utilizes organic compounds present in POME to generate microalgae biomass for algae oil production [50]. There are several environmental and operational factors, which can affect the microalgae growth in order to make the cultivation fruitful. The natural effluent discarded from palm oil mill might be colloidal, dark and viscous, which should be considered prior media preparation for culturing the microalgae [53]. Vairappan and Yen [54] had found that for the marine *Isochrysis* sp., the concentration of POME at 5% dilution is the best concentration for culture media due to properties of POME. This dilution procedure will then enhance the light penetration into media for the algal growth in wastewater [55]. As described in **Table 5**, limited growth conditions are required for the growth of microalgae using palm oil mill effluent.

The concentrated nutrients (i.e., C, N, P, carbohydrate, lipid, protein and minerals) in POME are highly applied in biotechnology studies for growing microalgae [46]. The concentration extend about POME in various accepting water body may give high effect on the aquatic environments if the release surpasses the limit of standards set by Malaysia Environmental Quality Act.

Microalgae	Nutrient reduction (%)	Lipid production (%)	Growth rate (d^{-1})	Biomass productivity (g/L/d)	Duration (d)	Ref.
C. pyrenoidosa	—	42	—	2.19	18	[56]
Chlorella sp.	—	—	0.066	0.058	15	[57]
S. platensis	—	—	—	9.8	13	[57]
C. sorokiniana	—	28.27	0.099	8.0	20	[58]
C. pyrenoidosa	COD, 71.16%	68	1.8	0.13	10	[28]
Chlorella sp.	—	—	—	1.562	7	[59]
A. platensis	—	—	—	0.211	7	[60]

Table 6. Microalgae growth in POME.

Numerous species of microalgae exist in freshwater, seawater or brackish make them appropriate to be grown in great scale reactor on unfertile lands. The usage of macroalgae and microalgae in the utilization or remediation of the excess nutrients and CO_2 present in natural water resources, lagoons and ponds is called as phycoremediation [55]. This biological remediative treatment was introduced about 40 years ago when it was usually used in tertiary wastewater treatment [61]. The performance of microalgae growth cultivated in POME is shown in **Table 6**.

As seen from **Table 6**, Kamyab et al. [28] have done their studies by focusing on the nutrients reduction in POME, lipid production and microalgae growth. Meanwhile, it can be found that other researchers have not focused much on nutrient reduction, which is to be considered more important in relation to the growth of microalgae.

3. Conclusion

Malaysia is the biggest generator and exporter of palm oil. Palm oil processing is achieved in palm oil mills where oil is removed from a palm oil fruit bunch. Expansive amounts of water are utilized throughout the extraction of crude palm oil from the fresh fruit bunch, and around half of the water consequences in POME, which is a highly polluting wastewater that pollutes the environment if discharged directly due to its high COD and BOD concentration. In conclusion, the research was carried out mainly to investigate the influence of discharging POME from the treatment plant especially in tropical region like Malaysia and the effect on microalgae growth efficiency in POME. In other words, a combination of wastewater treatment and renewable bioenergies production would be an added advantage to the palm oil industry.

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Conflict of interest

The authors declare that there is no conflict of interest.

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