The Planter, Kuala Lumpur, ***97*** *(1138): 35-42 (2021)*

POME Treatment Technology Using Biological and Physical Methods: A Review*

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Palm oil mills have been identified as one of the main sources of environmental pollution as they generate both solid (decanter cake) and liquid [palm oil mill effluent (pome)] wastes. It is vital for the palm oil industry to implement effective measures in order to mitigate its environmental impacts. The chemical oxygen demand (COD) and the biological oxygen demand (BOD), of the effluent daily analysed by the mill laboratory are important parameters related to the intensity of the environmental impacts on the wastewater. The organic content in the effluent contributes towards the BOD and its relevance lies in the oxygen content of the water courses (usually rivers) into which the effluent is discharged. At values in excess of 100 ppm in the effluent stream, the water source will face starvation of oxygen resulting in the destruction of their marine life. POME can be treated with algae or specific aquatic plants. Past researches were carried out on the potential of Chlamydomonas incerta, Pistia stratiotes, Ipomoea aquatica, Chrysopogon zizanioides *and* Eichhornia crassipes *in combating environmental concerns. The result shows that* Eichhornia crassipes *is able to reduce COD, BOD, N and P by up to 50, 90, 88 and 64 per cent respectively. Meanwhile, palm oil mill effluent (POME) can be treated by composting, a physical method using the plant* E. crassipes, *which was found to be the most effective biological method for POME treatment because its effectiveness in reducing contaminants was higher than other aquatic plants and microalgae. This review discusses several potential methods that are accepted and observed in other related researches and how biological methods compare with physical method for POME treatment.*

Keywords*: Palm oil mill effluent, aquatic plants, phytoremediation, biological method, physical method.*

The oil palm industry in Malaysia is committed to achieve sustainable management of oil palm plantation in order to conserve the environment since Malaysia is the second largest palm oil producer in the world. Typically, palm oil mills produce approximately 0.65 tonne of liquid waste [palm oil mill effluent (POME)] per tonne of fresh fruit bunch (FFB) processed. Raw POME entails high biochemical oxygen demand (BOD) of about 25 000 ppm (mg/L) and chemical oxygen demand (COD) of about 60 000 ppm (mg/L) – considered very high when compared to the municipal sewage (Zafar, 2018). The major problem lies in the production of high volume of liquid waste containing solids generated during the biological digestion process in the effluent treatment ponds. Therefore, POME is commonly treated *via* biological processes in anaerobic treatment plants followed by aerobic digestion ponds and finally facultative ponds in order to abide by the threshold limit set by Department of Environment (DOE). However, most of the time, the ponding system is still inefficient. This

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paper reviews biological treatment methods and considers their potential for use.

WASTAGE FROM THE OIL PALM

There are two types of wastes; solid and liquid by-products generated by the palm oil mills. All solid by-products are obtained from fruit bunches (Bakar *et al*., 2016) while the liquid wastes, also containing solids generated by the effluent digestion process known as POME are generated during the oil and kernel extraction process. POME requires intense treatment before being discharged into the rivers, other water course or land as it is considered a pollutant. In Malaysia, the DOE is the regulating body responsible in enforcing the Environmental Quality Act (1997) on the quality of the effluent discharged from the oil palms. The current ceiling on the BOD of the POME discharged into the watercourse is 100 ppm but the states can implement much lower values in areas sensitive to marine life.

POME source from processing

The three sources of POME are generated by the three process stations. The processes are sterilisation (typically 20%), clarification (typically 40%) and hydro cyclone (4%) (Lorestani, 2006). The ratio given in brackets are the proportion (by weight) of the POME components as percentage of FFB processed.

The first process in palm oil milling after the delivery of the FFB is pressure cooking the FFB as soon as possible to inactivate the enzyme lipase that is responsible for the synthesis of free fatty acid (FFA) of the oil residing within the fruit and the synthesis is highly accelerated once the fruit is ruptured. Inactivating the lipase can be done at very low temperatures of about 70^0C for a duration of about one hour but pressure cooking is done at 130^0C for a period of 90 minutes under steam pressure of 3 bar (g). This is done to condition the fruit mesocarp as well as to dry the kernel within the nuts. During the pressure cooking stage some of the steam will condense when releasing the heat to the fruits and the weight of this condensed steam mixed oil, wax, gum and other contaminants will amount to 15 per cent to 20 per cent of the weight of the FFB under sterilisation. This is not allowed to be recycled under good milling practice (GMP).

The second source of POME is the clarification station where the diluted crude oil discharged from the bottom of a settling tank containing about 4 per cent to 6 per cent oil called sludge is processed to recover the residual oil. The quantity is approximately 40 per cent as a ratio to the FFB processed.

The third source of effluent is wastewater from the hydrocyclone which is a physical separator of a mixture of two or three phases which have distinct specific gravities. In this case, the separation of two solids is done in a water bath. Water added for this process will be discharged when it becomes highly contaminated and this amounts to about 4 per cent as a ratio to FFB.

POME quality

POME is also made up of suspended and disintegrated solids called sludge. Sludge has higher nutrient contents compared to slurry (Zakaria, 1994). The sludge emits a fetid scent and can be dried and applied as manure or even used to promote microalgal growth since it contains high nutrient (Chooi, 1984) such as nitrogen, phosphorous, sodium, magnesium and calcium (Yacob *et al*., 2006). POME comprises 0.6-0.7 per cent palm oil, 95-96 per cent water, 4-5 per cent total solid and 2-4 per cent suspended solids (Irvan, 2018). The main components that contribute to high COD and BOD values in POME are the high amount of wastewater and oil and grease from the milling process. As a rough estimate, more than 85 per cent of the palm oil mills in Malaysia utilise the ponding system because of its low cost and easy maintenance aside from its proximity to the mills (Ma *et al*., 1993). However, it demands long retention time and large areas where problems could arise due to inability of wastewater to reach the discharge standard of 50 mg per litre BOD as the solids start to build up in the anaerobic pond. The wastewater contains viscous mixture of sediments, high hydrocarbon concentration, and the heavy phase is known as sludge (Prakash *et al.,* 2015). FFA of the oil in the anaerobic pond may range between 10 per cent to even as high as 80 per cent (Bakar *et al*., 2016). It will also contain other impurities including alkanes, aldehydes, ketones phenol and furan (Ainie *et al*., 1995). Recent application of sludge oil is its conversion to bio-fuels. However, it is still being sold as low grade manufacturing product (Bakar *et al*., 2016).

POME TREATMENT

Biological treatment

In 2019, Malaysia produced more than 16 million tonnes of palm oil which in turn contributed to high POME production. Many methods are available to address the environmental pollution caused by the POME; the effectiveness of which are not well documented mainly due to their inconsistency.

Biological method appears to be effective in eliminating suspended solids, organic matter, and oil and grease which are the main contributors of BOD. Moreover, this method is low in cost, has high organic loading capability and requires low energy. Additionally, the microorganism's habitat in POME has demonstrated its ability to assist in the bio-conversion of POME to normal water. Aquatic or semi-aquatic plants are also used in the wastewater treatment as they may remove unwanted nutrient, lower COD and BOD and they are also capable of removing toxic pollutants in freshwater and sea water (Hadiyanto *et al*., 2014).

It is imperative for the plant to possess certain traits, including high survival rate in many climatic conditions and changes. Specifically, the floating aquatic plants have been reported to attain high nutrient removal efficiency because of their affinity for high nutrient uptake, high biomass productivity and high rate of growth (Reddy & DeBusk, 1987). Algae can be used in treating the agriculture wastewater like POME (Kamyab *et al*., 2015a). Microalgae absorb light energy and have been used for cell synthesis as they are able to convert inorganic molecules into simpler sugar as an energy source for cell metabolism (Khan *et al*., 2009).

Microalgae are capable of eliminating a broadspectrum of pollutants in wastewater such as nitrogen and phosphorus (Bhatnagar *et al*., 2010) since these two are the major nutrient requirements for algae which are present abundantly in POME (Gualtieri & Barsanti, 2006) which may cause severe damage to aquatic lives.

Bioremediation

Bioremediation is a developing technology executed to remediate soil. It is defined as the process of using microorganisms to mitigate the environmental pollutants. This method ensures minimal exposure to public or site personnel. Phytoremediation is an emerging technology facilitated by aquatic plants and microbiota such as microalgae to eliminate low to moderate level of environmental contamination (Avsar *et al.*, 2007). It is defined as the use of green plants to reduce the environmental pollutants without having to expunge the contaminants. Plants are known to possess hyper accumulators that monitor metal uptake, accumulation, trafficking and detoxification in soil and water effectively (Singh *et al.*, 2003). The phytoremediation mechanism depends on availability, type of contaminants and soil properties.

Physical treatment

Composting

Composting provides an efficient way to treat sludge palm oil (SPO) by monitoring its temperature, pH, oxygen level, moisture level and carbon/nitrogen (C/N) nutrient ratio (Prakash *et al.*, 2015) under controlled temperature. The increase in the solubility of the contaminants will raise the temperature of the compost pile due to compost metabolic activity (Gibb *et al.*, 2001). Besides, the SPO contains high content of deteriorating materials and these microorganisms utilise the hydrocarbons as substrates prompting a rise in temperature caused by the metabolic activity (Marín *et al.*, 2006).

Secondly, another factor that may affect composting is the pH as it affects the degrading performance of the fungi and bacteria in the SPO (Sarika *et al.*, 2015). Also, phosphorous and nitrogen promotes microbial degradation of SPO component. In addition to that, oxygen level also helps in the breakdown of SPO components in the presence of oxygenase for which free oxygen is needed. When free oxygen is available, the natural microbial hydrocarbon degradation will be efficient (Ward *et al.*, 2003). Therefore, in a compost environment, the oxygen uptake rate provides the most dependable values of microbial activity (Gea *et al.*, 2004).

In addition, the moisture level also affects the composting process where the best water content for aerobic bioremediation treatment matrix is typically between 10 per cent and 20 per cent by mass (Hinchee & Arthur, 1991). Another factor includes C/N ratio where in order to obtain a suitable moisture and C/N ratio, the different lignocellulosic are mixed in the sludge (Prakash *et al.*, 2015). The increment in the nitrogen content of the compost leads to a positive correlation with the utilisation rate of cellulosic material (Thambirajah *et al.*, 1995).

Aquatic treatment

Efficiency of Chlamydomonas *in the removal of pollutants from POME*

Chlamydomonas incerta is known as the microalgae that has the fastest growth among all other microalgae. It also has high ability in eliminating pollutants from the POME. The highest removal of nutrients rate is 250 mg per litre of POME with microalgae *C. incerta* was about 67.35 per cent concentration of COD (Kamyab *et al.*, 2015a). This was demonstrated at a fixed temperature and photoperiod where nitrogen took a vital part in accumulation of lipid for microalgal cells. The outcome of this research shows that *C. incerta* can be an acceptable species to eliminate harmful components in POME. The procedure of microalgae cultivation in POME through efficient and effective treatment will reduce cost, energy and greenhouse gas emission (Kamyab *et al.*, 2015a). For upcoming research, *C. incerta* may be contemplated as suitable microalgae as it can be easily cultivated in POME and is immensely present in Malaysia throughout the year (Kamyab *et al.*, 2015b).

Phytoremediation of POME using **Pistia stratiotes** *and algae* **Spirulina sp** *for biomass production*

Apu-apu or *Pistia stratiotes* plant is smaller than *Eichhornia crassipes*. The leaves are wide, enabling it to cover larger area of waste absorption. COD content, nitrogen and phosphorus in POME decreased by increasing the retention time (up to 6 days) and activated sludge percentage (35-65%) by using water lettuce plant as the first remediation while using *Spirulina* as the second remediation (Hadiyanto *et al.*, 2014).

Influences of activated sludge concentration on COD reduction in POME

Anaerobic bacteria are the most important factor in activating the breakdown of organic content in POME. In addition, activated sludge consists of two environmental zones, the aerobic and anaerobic zone. Anaerobic microorganisms can develop without the presence of oxygen and nitrate where, they are able to break down from complex organic source into simpler organic matter. This simple organic matter is then utilised as source of nutrient for metabolism (Hadiyanto *et al.*, 2014). Long retention time bring about phosphorous reduction to up to 18 per cent within 6 days' period for diverse activated sludge contents. The longer holding time and increasing sludge ratio will give greater cycle for water lettuce and organic bacteria in sludge. Meanwhile, nitrogen in the form of N-organic and ammonia (NH_3) will be converted into nitrite molecules by bacteria. Then, the water lettuce will utilise it for photosynthetic reaction. It is demonstrated that the amount of nitrogen reduced in 1-5 days with 35 per cent to 65 per cent of activated sludge is between 17.73 per cent to 30.78 per cent (Hadiyanto *et al.*, 2014).

Suitability of **Ipomoea aquatica** *for the treatment of effluent from palm oil mill*

Phytoremediation of *Ipomoea aquatica* is able to decrease the concentration of COD, nutrients and aerobic suspended solid of POME to up to 80 per cent by the end of 25 days of treatment. In a research by Sa'at and Zaman (2017), *I. aquatica* was used as the aquatic plant for its viability near palm oil mill treatment pond along with high growth rate, deeper growing root zone. *I. aquatica* was demonstrated to be the most efficient remover of pollutant among water hyacinth, water lettuce, and duckweed: removing 80 per cent of COD, 90 per cent of total suspended solids (TSS) and 99 per cent of nutrients after 25 days of treatment. The reduction is said to be contributed by phytodegradation mechanism which digests organic contaminants *via* plant enzymes or plant metabolic activities (Saat & Zaman, 2017). Therefore, the potential of *I. aquatica* can be further explored for their nutrient accumulation.

Phytoremediation potential of vetiver system technology for improving the quality of POME

Vetiver grass (*Chrysopogon zizanioides* L.) belongs to the same family as maize and sugarcane. Recently, vetiver's role has been successfully expanded to wastewater treatment as it has robust morphological and physiological characteristics towards adverse conditions (Darajeh *et al.*, 2014). Vetiver plant absorbs essential plant nutrients such as nitrogen, phosphorus, and cations and reserves them for other usage (Darajeh *et al.*, 2014).

Also, Darajeh *et al*. (2014) stated that the vetiver plant uptake relies on the level of contaminants. Within 2 weeks of remediation, the highest reduction in BOD was in low concentrated POME (LCP) at 96 per cent while for high concentrated POME (HCP) it was at 62 per cent. Meanwhile, COD was reduced significantly throughout the growing time because of excellent growth of root systems. The results reveal that LCP had the highest reduction of COD with up to 90 per cent, while phytoremediation in HCP depicts lower reduction of COD of up to 30 per cent. Hence, the phytoremediation in LCP was more productive than in HCP as for higher decrease in BOD and COD.

DISCUSSION

Phytoremediation of POME by aquatic plants and microalgae for biomass production

Water hyacinth or *E. crassipes* is efficient in reducing pollutants and nutrients in POME of up to 90 per cent due to flexible root structure and multiple stomata rendering more acquisition of carbon sources, nitrogen, phosphorous for photosynthesis (Debusk & Dieberg, 1989). It has also been listed as an efficient and economical adsorbent for effluents from the textile industry due to its ability in reducing colours, heavy metals and lowering certain other physiochemical parameters like TSS, total dissolved solids (TDS), COD and BOD in textile wastewater (Priya & Selvan, 2017). Meanwhile, *Azotobacter chroococcum* is a bacterium that grows in water hyacinth roots that helps to digest the complex compounds of nitrogen into nitrate ions during the process of phytodegradation. Eventually, this process leads to faster nitrogen absorption. As for *Spirulina platensis*, the highest reduction of COD was from 1260 to 620 ppm (50.79 %) due to the nutrient availability contributed by its cultivation (Hadiyanto *et al*., 2013).

Cultivating *E. crassipes* in ponds

A palm oil mill processing 60 tonnes FFB per hour and operating 20 hours a day will process 1 200 tonnes of FFB per day producing 60 per cent or 720 tonnes of POME. Therefore, a system needs to be implemented to treat the large quantity of POME so that when discharged into the waterways, the aquatic life can survive. One of the ways that can be done is by cultivating *E. crassipes*. *E. crassipes* may thrive in a variety of climates especially in temperatures of 20 - 35°C, with a pH tolerance in the range of 5 - 8. The plant grows extremely fast under favourable conditions where it may double within 6 - 15 days. The plant should be taken care of extensively if it is going to be introduced into new ponds. However, it is very manageable when cultivated in confined areas. However, it is extremely important that when removing any plant material from the pond, it is not released into any other water course (Westphal, 1989).

CONCLUSION AND RECOMMENDATION

Based on the current findings, *E. crassipes* (water hyacinth) appears to be the most promising biological method for POME treatment due to its high potential in mitigating wastewater pollution as compared to aquatic plants and microalgae. While the physical method of composting remains the most effective, it is however, costlier than *E. crassipes* that can be bought at only RM20 for every 100 bags as an inception unlike vetiver that cost RM28 for every 8x8 polybag and *Chlamydomonas* at RM39 per bag. Mills may try to incorporate *E. crassipes* for the treatment of POME because it may preserve the nutrients by acting as bulking agents. It has also been extensively studied for its efficiency and economical attributes of remediation of polluting elements in the effluent.

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