Palm Oil Mill Effluent

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Palm oil mill effluent (POME) requires treatment prior to discharge to the environment. Biological processing technology is highly preferable due to its advantages of environmentally friendliness, cost effectiveness, and practicality. These methods utilized various designs and modifications of bioreactors fostering effective fermentation technology in the presence of fungi, bacteria, microalgae, and a consortium of microorganisms.

palm oil mill effluent | bioenvironmental factor | biological treatment | fungi | bacteria | microalgae | Lysinibacillus sp.

1. Introduction

Major cooking oils in the world are made up of palm oil, olive oil, canola oil, soybean oil, and sunflower oil. According to Oil World (2021), it is predicted that the world production of the four major vegetable oils will increase by circa seven million tonnes by 2021 and 2022 [1]. In 2021, 16,666,635 tonnes of crude palm oil were produced in Malaysia [2]. This was due to the high number of mills actively in operation within Malaysia, reaching up to 452 mills with a total processing capacity of 112.91 million tonnes of fresh fruit bunch (FFB) per year [3]. The operation of palm oil mills generates a significant amount of palm oil waste, and it is expected that 41,666,587.5 to 58,333,222.5 tonnes of POME will have been generated in 2021. This is because approximately 2.5 to 3.5 tonnes of POME are generated for every tonne of crude palm oil produced [4].

Even though Malaysia has benefited financially, palm oil milling has significantly contributed to environmental degradation both at the input and the output sides of its activities [5]. Due to the high amounts of solids, biochemical oxygen demand (BOD), chemical oxygen demand (COD), grease, and nutrients in POME, the direct discharge of the waste contributes to aquatic and land pollution. If the waste is left untreated, it can lead to rapid deoxygenation in waterbodies, thus, the ecosystem sustainability and biodiversity of the aquatic and land environments would be obstructed. The rapid growth of the palm oil industry in Malaysia and its competition with neighbouring countries such as Indonesia, has led to the tightening of environmental regulations. In this regard, the Malaysian government has taken an initiative by enacting the Environmental Quality Act 1974 to prevent, abate, and control pollution [6]. Therefore, the effluent generated from the palm oil mills needs to be treated before being discharged into the environment.

The environmental issues associated with the disposal of POME have demanded the top palm oil producer countries to reassess and re-establish their waste management policies by utilizing advanced biotreatment technologies [7]. In recent times, the treatment technologies for palm oil mill waste have been extensively re-established to ensure that palm oil mill run-off can be utilized sustainably [8]. Previously, the objective of treating the palm oil mill waste was largely for the purpose of complying with government regulations, but the awareness of needing to protect the environment has now been raised among individuals, organizations, and governments. The utilization of various industrial wastes for the production of other value-added products via biological processing is deemed practical and has been widely applied by many researchers [9][10][11][12][13][14]. This is because those wastes have the potential to be utilized due to degradable organic compounds, whereby a net positive energy gain could be achieved with a proper utilization strategy [15].

Palm oil mill waste treatment technologies have been fostering biological microorganisms, physicochemical methods, coagulation, membrane, and thermochemical processes. Biological processing for POME treatment offers low-cost, practical, and easy procedures [8], while other techniques that are implemented to treat POME include anaerobic ponding systems, integrated anaerobic–aerobic bioreactors, coagulation and flocculation, vermicomposting, membrane filtration, moving bed biofilm reactors, and zero liquid discharge [16]. The common biological processing involves anaerobic treatment, aerobic digestion, and fermentation [8], but the selection of the biological treatment methods is dependent on the ability to reduce the BOD, COD, and organic nutrients in the waste discharge.

Although there have been many promising achievements at the laboratory or pilot scale, there are several challenges to implement the POME biological treatment at the industrial scale. One of the major hindrances is the upscaling of the bioreactor, which involves the considerations of cost production, total working volume, hydraulic retention time (HRT), practicality, and processing technology effectiveness in the presence of microorganisms. By combining several strains of microorganisms with certain bioreactor designs, however, researchers have shown remarkable reduction in the BOD, COD, and organic contents prior to discharging the waste. Meanwhile, chemical and physical treatment approaches encounter limitations in terms of harmful chemical utilization and the occurrence of pore blocking at the membrane filtration surface.

2. Characterisation of POME

Every tonne of crude palm oil produced generates approximately 2.5 to 3.5 tonnes of POME [4]. POME is the only liquid waste produced from palm oil processing, which can be characterized as a brownish sludge with high viscosity that is composed of fine cellulosic materials, oil, and water. The brownish colour of the sludge is attributed to the fulvic acid-like components, and humic acid [17]. POME is generated from the sterilization of FFB, clarification of crude palm oil (CPO)and hydro-cyclone separation of the kernel, and can be obtained from the clarification of wastewater, sterilizer condensate, and hydro-cyclone wastewater [18][19][20]. The general characteristics of POME from different sources are tabulated in **Table 1**.

Table 1. General characteristics of POME and its respective standard discharge limit by the Malaysian Department of Environment.

Parameters	**Concentration Range**		
	[20]	**[21]**	**[22]**
Chemical oxygen demand (COD)	15,000–100,000	51,000	100
Biochemical oxygen demand (BOD)	10,250–43,750	25,000	50
Total suspended solids (TSS)	5000–54,000	18,000	400
Ammoniacal nitrogen	4–80	35	100
Oil and grease	130–18,000	6000	50
Total nitrogen	180–1400	750	200
pH	3.4–5.2	4.2	5.0

All values, except pH and temperature, were expressed in mg/L.

3. Biological Processing Technologies for POME Treatment

Biological processing technology implies the use of microorganisms to degrade complex organic matters present in the wastewater. Alternatively, it is also termed as a secondary treatment. The purpose of biological processing technologies for wastewater treatment is to remove pollutants such as organic carbon, nutrients, heavy metals, suspended solids, and inorganic salts by degradation biologically in the presence of microorganisms. The complex organic matter in the wastewater is oxidized into the cells of the microorganisms such as bacteria, fungi, or algae under anaerobic or aerobic conditions and subsequently eliminated by the removal process or sedimentation [23]. The sediment can be valorised to other value-added products such as biomass fuel [24].

The biological reaction happens in the bioreactor. Generally, the wastewater will be introduced into a designed bioreactor in which the organic matter will be utilized by the microorganisms. The design of the bioreaction is dependent on the required end product. This is because a high yield of the bioprocess can be achieved once an optimum external environment meets the needs of the biological reaction system [24].

Bacteria are the most typical microorganisms responsible for the stable end product of the biochemical decomposition of wastewaters [25]. Nutrients, organic substances, and pollutants available in the wastewater are utilized as food by the microorganisms to carry out metabolism. The microorganisms decompose the organic matter through two different multitudinous bioconversion routes, namely, biological oxidation and biosynthesis [26]. The biological oxidation forms some end-products, such as minerals, that remain in the solution and are discharged with the effluent (Equation (1)) [22].

Biological oxidation:

$$\mathrm{COHNS\ (organic\ \ matter) + O_2 + Bacteria\ \rightarrow\ CO_2 +\ NH_3\,(with\ \ energy) +\ End\ \ products} \tag{1}$$

The biosynthesis transforms the colloidal and dissolved organic matter into new cells which appears in the form of dense biomass that can be removed by sedimentation (Equation (2)) [22].

Biosynthesis:

$$\mathrm{COHNS\ (organic\ \ matter) +\ O_2 +\ Bacteria\ \rightarrow C_5H_7NO_7\,(new\ \ cells\ \ or\ \ biomass)} \tag{2}$$

Biological processing methods can be categorized into two methods, the anaerobic method and the aerobic method. The classification of the above-mentioned biological treatment methods is based on the content of dissolved oxygen in the wastewater. Aerobic biological treatment takes place in the presence of oxygen, while anaerobic biological treatment takes place in the absence of oxygen.

Aerobic biological treatment includes aerobic bioreactors, activated sludge, percolating or trickling filters, biological filters, rotating biological contactors, and the biological removal of nutrients [22]. The presence of oxygen allows the microorganisms to convert the organics and carbon dioxide into new biomass. In the past, aerobic biological treatment was aimed at the oxidation of organic material (collectively measured as BOD) and the oxidation of ammonium ($NH4^+$) [27]. At present, aerobic biological treatment is commonly used to polish the industrial wastewater pre-treated by anaerobic processes [28]. The application of aerobic biological treatment after the pre-treatment of the industrial wastewater will guarantee that the wastewater is fully degraded. Concomitantly, the industrial wastewater can be discharged safely in compliance with strict environmental regulations.

Anaerobic biological treatment includes anaerobic lagoons and anaerobic bioreactors. This treatment is commonly applied for high strength wastewater with high biodegradable organic matter whereby the aerobic treatment would be inefficient. This is because the oxygen demand for the aerobic condition to be maintained during the treatment of wastewater could not be fulfilled [26]. The anaerobic treatment offers many advantages when compared to aerobic treatment, viz., a low energy input, low nutrient requirement, and the degradation of waste organic material that leads to the production of biogas energy; however, the anaerobic biological treatment of POME also has its own drawbacks, such as a long HRT.

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