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A Review on Aerobic Biological Processes for Palm Oil Mill Effluent: Possible Approaches

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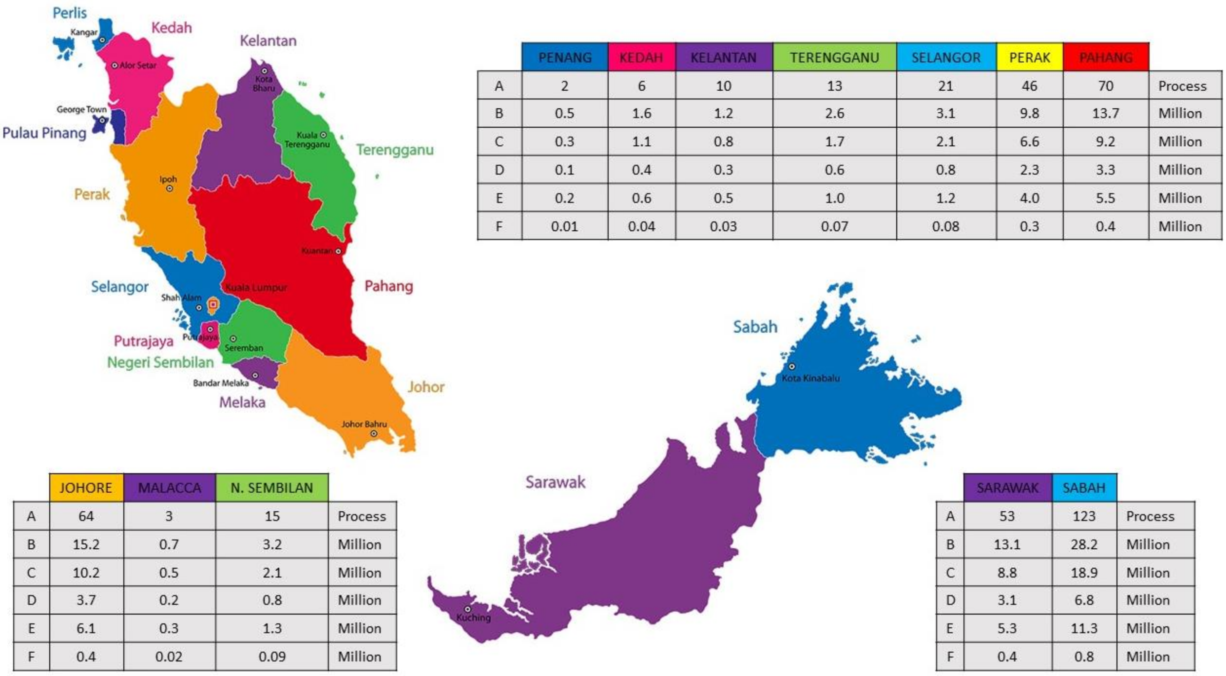
Abstract. On large scale, many countries like Indonesia and Malaysia receive economic advantage from employing numerous mills to produce and sell palm oil. Despite the benefits, contaminated effluents from palm oil processing have polluted enormous quantities of fresh water, which leads to massive scarcity of fresh water. Moreover, vast quantities of fresh water with steady rainfalls were placed in a country known as Malaysia, but currently, it has massive fresh water wastage because of environmental pollution, and discharging unwell treated palm oil mill effluent (POME). Also, the increasing amounts of POME suffocate agriculture, fresh water, aquatic life, and human health and results in a fantastic medium for bacteria, viruses, and diseases growth. Therefore, palm oil mill effluent receives huge attention since treatment technologies are highly cost, which forces palm oil industries to reuse wastewater in several needs and conserve the available fresh water. Presently, palm oil industries are looking for treatments with low costs, low energy consumptions, and good performance to boost a greener image of palm oil production. This review shows and summarizes most of the possible approaches of aerobic biological treatments to decompose POME, showing their advantages and disadvantages. Finally, this review finds developing a hybrid system comprised from number of aerobic biological treatments can defeat stand-alone technology limitations and improve effluent quality.

1 Introduction

For decades, water is known as the main source of life, but it’s a major source of illness and probably death in the present. Human health, marine life, and fresh water supply are undoubtedly threatened and worse in the near future, particularly in industrial areas, and highly populated cities [1]. Crowded cities demand vast amount of clean water, leading to huge quantities of wastewater streamed into the environment. There are 1.1 billion of people missing a proper access to good quality drinking water, according to WHO report at 2007. In the next 50 years, 40% or more of the population will face water scarcity [2][3]. Hence, management and control of water pollution have become highly important and processing of contaminated water must take a place with high quality strategy to reduce fresh water shortage.

Milling process of oil palm requires vast amount of water to produce crude palm oil (CPO). In order to produce one ton of CPO, about 5 to 7 ton of fresh water are consumed, also half of the fresh water used (2.5 to 3.5 ton) is streamed as palm oil mill effluent (POME) [4][5][6]. The produced wastewater from palm oil industries named as palm oil mill effluent is highly polluted having high range of suspended solids, chemical oxygen demand (COD), biochemical oxygen demand (BOD), turbidity, and contaminated with microbes, so that opting a treatment is an important step [7]. POME is a thick brownish colloidal mixture of solids, oil, and water at fresh state [8]. In Malaysia, large area is employed for series of open ponds processing POME in terms of polishing, aerobic, anaerobic, facultative, acidification, equalization, and de-oiling. Ponding system for POME has many advantages such as low maintenance cost, and low operating energy. Despite that, ponding system has several disadvantages like, requires vast area, no facilities to capture biogas, and hard to control nearby urban areas. In below, an overview of the Malaysian palm oil industry including number of milling processes, and wastewater amount in year 2011.



	PENANG	KEDAH	KELANTAN	TERENGGANU	SELANGOR	PERAK	PAHANG	
A	2	6	10	13	21	46	70	Process
B	0.5	1.6	1.2	2.6	3.1	9.8	13.7	Million
C	0.3	1.1	0.8	1.7	2.1	6.6	9.2	Million
D	0.1	0.4	0.3	0.6	0.8	2.3	3.3	Million
E	0.2	0.6	0.5	1.0	1.2	4.0	5.5	Million
F	0.01	0.04	0.03	0.07	0.08	0.3	0.4	Million

	JOHORE	MALACCA	N. SEMBILAN	
A	64	3	15	Process
B	15.2	0.7	3.2	Million
C	10.2	0.5	2.1	Million
D	3.7	0.2	0.8	Million
E	6.1	0.3	1.3	Million
F	0.4	0.02	0.09	Million

	SARAWAK	SABAH	
A	53	123	Process
B	13.1	28.2	Million
C	8.8	18.9	Million
D	3.1	6.8	Million
E	5.3	11.3	Million
F	0.4	0.8	Million

Figure 1. An overview of the Malaysian palm oil industry in year 2011 [7]. A- Number of processing mills; B- Amount of processed fresh fruit bunch (FFB) by mills; C- POME amount; D- amount of Sterilizer condensate; E- Amount of clarification wastewater; F- Amount of hydro cyclone wastewater. Note: B, C, D, E, and F are in ton units

Polishing process of POME is important to deliver high quality treatment in removing color, total suspended solids, and organic matters. Most of the available treatments are uncappable of producing well treated POME because of operating and maintenance costs and low efficiency. Also, there are some considerations about the final treated POME, which is still having dark brownish color, and considerable concentration of COD and BOD related to the high amount of total suspended solids. Hence, discharge limit enforcement had come into to protect the environment and the public health. Zahrim et al. (2009) treated POME by using activated sludge method inside sequencing batch reactor (SBR) [9]. It removed 0-14% of color, and 27-39% of organic matter. Later, activated sludge had been used as a seed within granular activated carbon to implement a process known as attached growth. Attached growth is highly favored due to its ability to breakdown high organic load and requiring low cost compared to physical and chemical treatments. It attained 28-41%, and 59-70% of color and organic matter removal, respectively. The increase in the adsorption process was occurred due to biofilm growth. Furthermore, biodegradation and adsorption removed about 50% of all of POME pollutants. In 2010, Chan et al. used SBR to process anaerobically-treated POME. High retention of mixed liquor volatile suspended solids (MLVSS) and well acclimatization process led to good results in COD, BOD, and suspended solids (SS) removal [10]. Table 1 presents short description about some aerobic biological treatments with their efficiencies.

Table 1. Aerobic biological processes with their efficiencies, and process description [7].

System	Description	Efficiencies
SBR with suspended activated sludge	5 min Filling, 95 h reacting, 15 min settling, and 10 min sludge Decanting.	27-39% COD; 0-14% Color
SBR with activated sludge granular activated carbon	5 min Filling, 95 h reacting, 15 min settling, and 10 min Decanting.	59-70% COD; 28-41% Color
SBR	filling, 20 h reacting, 2 h settling, and decanting.	97-98% BOD3; 95-96% COD; 98-99% SS; 65 mL/g sludge volume index
SBR - constructed wetland system	Phase (1)- SBR process; phase (2)- constructed wetland system.	BOD3 < 20 mg/L
Suspended packing in activated sludge aeration tank, with complete mixing	Phase (1)- clarifier and gradual acclimatization of microbes in completely mixed activated sludge reactor; phase (2)- extended aeration; phase (3)- clarifier; and phase (4)- post-treatment (physicochemical treatment)	BOD3 < 20 mg/L
Extended aeration, coupled with fixed packing in activated sludge aeration tank	Phase (1)- extended aeration process followed by clarifier; phase (2)- activated sludge reactor; phase (3)- clarifier with returned activated sludge; and phase (4)- polymer dosing	BOD3 < 20 mg/L
Aerobic suspended and submerged attached growth	Phase (1) extended aeration process in activated sludge system; phase (2)- clarifier; phase (3)- aerated submerged fixed bed reactor; and phase (4)- sand filtration process	BOD3 < 20 mg/L
Aerobic suspended and attached growth	Phase (1)- extended aeration process in activated sludge system; phase (2)- clarifier; phase (3)- fixed bed reactor; and phase (4)- clarifier and sand filtration process	50-75% BOD3
Attached growth - roughing filter solid contact technology	Phase (1)- roughing filter tower; phase (2)- solid contact tank; and phase (3)- clarifier	BOD3 < 20 mg/L; organics 75%

Biological treatments are involved in many wastewater systems. Sometimes, a combination of two mechanisms are used such as, biological and physical, or biological and chemical. For example, Chong and Tan (2010) introduced a combination of SBR and constructed wetlands to discharge effluent having less than 20 mg/l of BOD3 [7].

2 Aerobic Biological Treatment

The biological treatment was unquestionable in the late 1800's, which got explained by Americans (Massachusetts, Drown and Sedgwick, Hazen, and Mills) and Europeans (Dibdin, Bailey-Denton, Frankland, and Mueller). Aerobic biological treatment (ABT) can be defined as the biodegradation of POME contaminants by microorganisms under aerobic circumstances. Microbes absorb organics and inorganics as a major food during the biodegradation to increase their population and size. Variety of organisms like protozoan, marshland plants, aquatic plants, plants seed, and bacteria were examined for playing an important role for the biotreatment. Bacteria or fungi are preferred in treating POME with using oxygen supply. Microorganisms of the aerobic biological treatment can remove high amounts of pollutants with low costs [11]. According to Mittal (2006), ABT can remove 90% of COD from effluents [12]. Other researches find using aerobic condition removes 98% and 93% of COD and BOD, respectively at 60 Hours of HRT [10][13]. It is considered friendly and economical because it does produce biomass which could be use as fertilizer, and biogas but currently, there is no single technology on planet earth to contain all these beneficial products [14]. Also, biotreatment of POME could be done in short time with low sludge production [15][16]. However, several factors affect the bioprocess stability such as, oxygen concentration, microorganisms, temperature, and organic load ratio. Aerobic biological process involves many POME treatments such as, aerobic facultative pond, aerated lagoons, SBR, biofilm treatment, microbial fuel cell (MFC), conventional wastewater treatment, trickling filters (Bio-towers), rotating biological contactors, and aerobic granulation technology. Table 2 presents benefits, dis-benefits, and waste product of rotating biological contactors (RBC), biological filtration, and activated sludge treatments.

Table 2. Advantages and disadvantages of some aerobic biological treatments

Treatment	Benefits	Disbenefits	Waste product
Activated sludge	handle medium to high concentrations of BOD and COD; rapid purification	critical sludge quality (bulking & rising can occur); Can produce odors; Critical rates of agitation and aeration; huge area required.	Sludge
Biological filtration	Low operation energy and flexible	Needs recycle to ensure treatment quality.	Sludge and odor
RBC	require space, suitable for low and medium strength effluents	Imbalanced loads could lead to Mechanical damage.	Sludge

ABT produces two kinds of byproducts, biogas and solid matters known as sludge [17]. Circumstances should be controlled and optimized to harvest the possible maximum amount of biomass and biogas [18]. Nevertheless, Schultz (2005) finds the benefits of ABT in having low operating and capital cost, and good removal of total nitrogen, ammonia, and sulfides [18]. ABT has been classified into fixed biofilm, and suspended growth (Unfixed biofilm) based on their type of biofilm. The best examples of fixed biofilms are RBC and trickling filters, while aerated lagoons and aeration tank with activated sludge are examples of unfixed biofilm. Usually, ABT of POME faces sudden rise in oxygen demand due a change or an increase in aerobic bacteria activity, population, and/or environmental conditions. Therefore, aeration systems are installed to supply ABT with sufficient oxygen amount and improve effluent properties. There are many sorts of aeration systems for ABT, such as diffused air, and surface aeration. Table 3 presents various aeration supply for POME treatment.

Table 3. Aeration systems for POME aerobic biological treatment [19]

Aeration system	Type	Description	Application
Diffused Air	Jet	Inject compressed air	Activated sludge; mixing and aeration equalization mixing tank; aeration in deep tank
	Static tube mixer	Short tubes with internal baffles	Activated sludge; aerated lagoons
	Sparger turbine	Compresses air injection and low speed turbine	Activated sludge; aerobic digestion
	Coarse bubble system	Bubbles are generated by shear plates, nozzles, or orifices injectors	Activated sludge; aeration chamber; aerobic digestion
	Fine bubble system	Bubbles are generated by flexible membrane (disks, or tubes, or dooms), or ceramic plastic.	Activated sludge
Surface aeration	Cascade	POME flows over a series of steps in sheet flow	Post-aeration
	Rotating disk assembly (Rotor brush)	POME absorbs oxygen by exposing to atmosphere through Blades or disks are rotated in POME	Aerated lagoons; channel aeration; oxidation ditch
	Aspirating	Inclined propeller assembly	Aerated lagoons
	High speed floating aerator	Expose POME droplets to atmosphere to capture oxygen but it has small diameter propeller	Aerobic digestion; aerated lagoons
	Low speed turbine aerator	Expose POME droplets to atmosphere to capture oxygen and it has large diameter turbine	aerated lagoons; Conventional activated sludge; aerobic digestion.

2.1 Facultative Ponds

A mixture of aerobic and anaerobic conditions is used in one pond to process POME named as facultative ponds [20]. Aerobic conditions are maintained at the top section of the pond, while anaerobic conditions are underneath the aerobic section. Figure 2 presents structure, aerobic zone, sludge thickness, and anaerobic zone of the facultative pond.

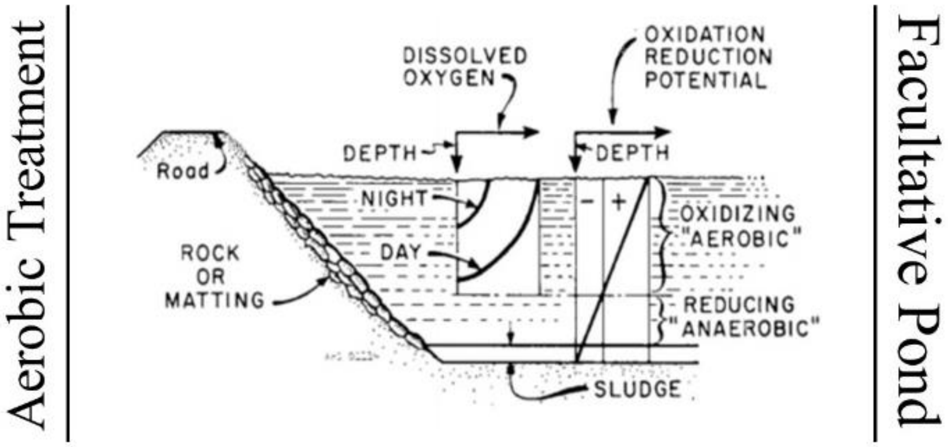


Figure 2. Typical cross-section of a Facultative Pond [21]

At the upper zone, ABT occurs by removing nutrients and BOD removal, nutrients. Meanwhile, the bottom zone has anaerobic treatment, which removes BOD concentration, performs denitrification, and digest sludge [20]. The oxygen mission is to keep and maintain aerobic conditions at the upper layer of the facultative pond. Algae has been found in the facultative pond performing the photosynthetic activity and discharging oxygen which makes the aerobic circumstances at the top zone. It grows naturally once there are appropriate circumstances (e.g., sun light). Moreover, it turns the influent color into green due highly amount of algae population.

The state of art of the facultative pond is that algae consume carbon dioxide for photosynthesis process, and discharge oxygen, while bacteria use this oxygen to decompose organic and inorganic molecules and discharge electrons [22][23]. Figure 3 demonstrates the cooperation between algae and bacteria in the facultative pond.

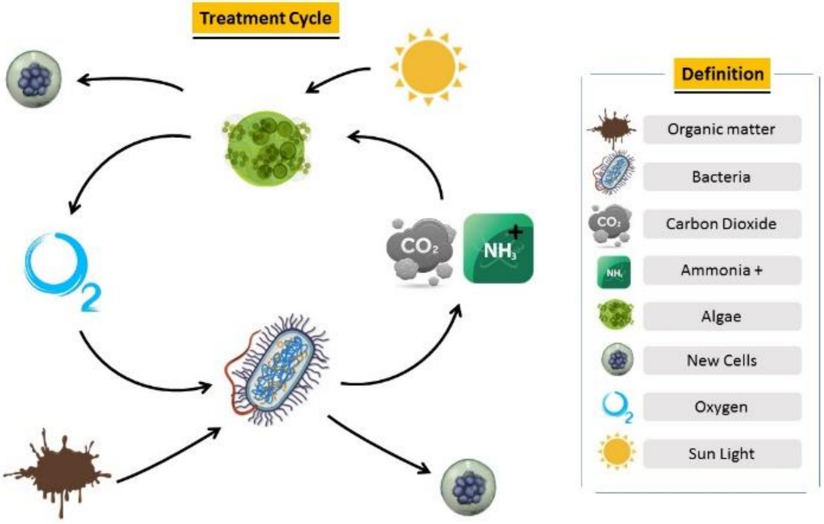


Figure 3. Facultative pond treatment cycle [22]

Dissolved oxygen (DO) can be various during anytime of the facultative process because DO range is dependent on the algae's photosynthesis which its reliant on light concentration. In addition, pH level of POME is changing due to the level of the algae's photosynthesis and it can reach a possible maximum range of 10. This variety in pH is occurring due fast removal of carbon dioxide by algae, while bacteria is slowly accepting algae's oxygen. Several scientists believe using facultative pond for POME is quite important to reduce BOD concentration since POME contains biodegradable matters, and that's giving good feature for facultative system [24][25]. Table 4 shows important factors that increase or decrease facultative pond performance.

Table 4. Major aspects impact Facultative pond efficiency.

Features	Description	Ref.
Depth	If the pond depth less than 1 meter, it would be ideal for emergence of vegetation. Meanwhile, if the pond depth greater than 1.5 meter, the oxygen amount will be blocked in too close zone to the pond surface, for that the biotreatment will be operated anaerobically. The recommended depth is 1.2 meter.	[22][25]
Sludge layer	The digestion process of POME sludge starts at temperature >15 ℃. The biogas is produced rapidly at temperature >22 ℃, and that would form mat at the pond surface which blocks light penetration. Desludging process occurs each 10-15 year.	[22]
Climate	The ideal climate to operate facultative pond is warm climate which leads to intense solar radiation, photosynthesis, high DO level and well temperature.	[22]
Mixing	Mixing process removes stagnant zone, and distributes oxygen, boosts algae growth, and leads to BOD removal. Thermal stratification would rapidly occur in the absence of mixing operation.	[22]
Retention time	The recommended retention time is 5 to 50 days, following the climate conditions.	N/A

2.2 Aerated Lagoons

It can be defined as lagoons utilized to contain wastewater and equipped with aerators to stream oxygen and maintain aerobic circumstances named as aerated lagoons or aerated basins. It doesn't involve algae in its ABT, so its distinguishable from the facultative ponds. Besides, dimensions of the basins are flexible ranging 2-6 meters in depth unlike the facultative ponds. However, aerated lagoons require sufficient retention time, enough surface area, and appropriate design. It has been reported that aerated lagoons may face difficulties for treating high COD concentration influent like POME because it has low population of microbes. Moreover, important factors should be considered for designing aerated lagoons like mixing, effluent quality, treatment performance, stability assessment, opting an aeration system, and dissolved oxygen concentration.

There are three types of aerators known as surface aeration, jet aeration, and diffused aeration that can be installed inside the aerated lagoons to feed POME with oxygen. Diffused aerators can be installed at the basin bottom to stream air inside POME, rise dissolved oxygen amount, and sustain the ABT. Besides, it discharges fine bubbles because it uses filter head made of ceramic or membranous [18].

Jet aerators owns a special feature to supply either aeration or mixing without the need to have additional tools. First, it streams amounts of air to the influent maintaining the aerobic conditions at the lagoon. It shuts off air flow once the dissolved oxygen level is satisfying. Then, jet aerator's pump delivers the needed mixing and saving the operation energy. This system presents a quiet and smooth operation, with no spray, splashing, or misting from the basin [18]. Figure 4 shows pictures of the jet aerators for wastewater treatment.

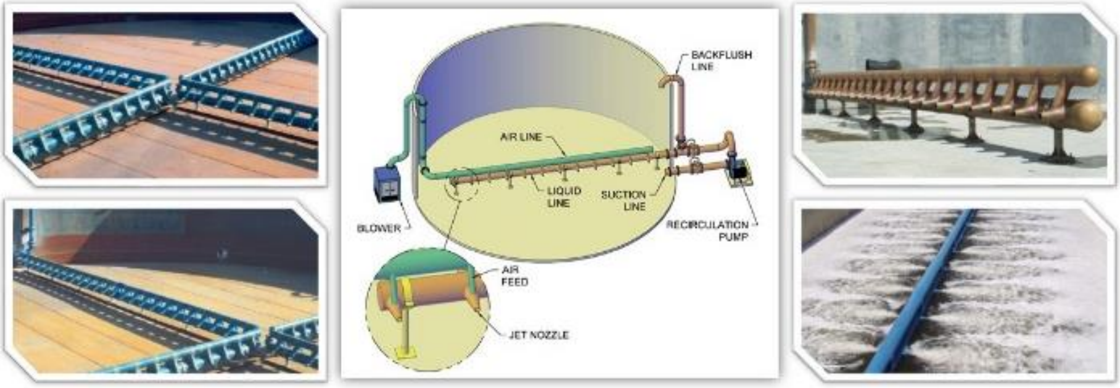


Figure 4. Jet Aeration system

The last type of aerators, surface aerator provides low and high-speed aeration to break down POME molecules to droplets spray and transfer the oxygen to it. It is considered efficient and could be operated in various aeration speeds. The oxygen dissolves through the atmosphere to POME spray droplets, and once the sprays have large surface area, the dissolving process of oxygen is getting optimized. It offers low operating cost for both low and high-speed aeration, and good ability to face extreme conditions like high temperature. Mounted aeration rotor (Discs) is an alternative for surface aeration system which is employed in horizontal level. These aerators have the ability to deliver high treated effluent, stable ABT, energy save and easy maintenance. Figure 5 presents pictures of aeration discs.

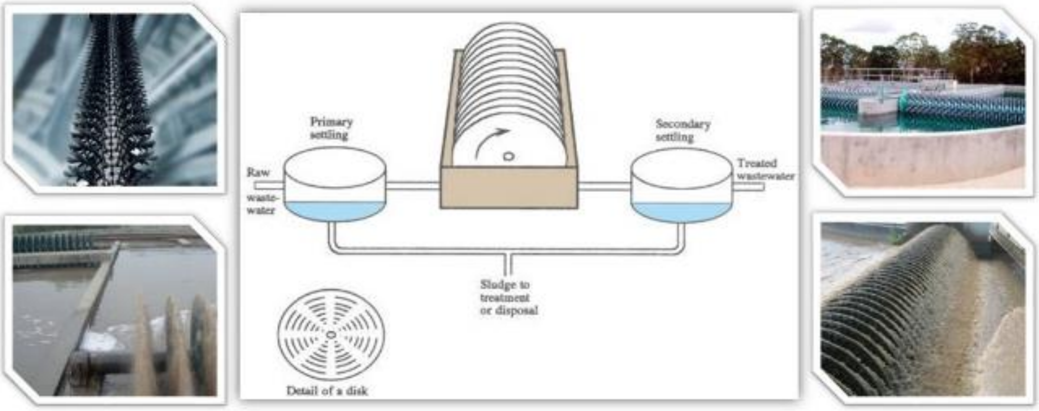


Figure 5. Aeration discs (Rotors)

2.3 *Sequencing Batch Reactor (SBR)*

SBR can deliver clarification process, fill and draw in one reactor basin unlike conventional activated sludge system requires more than one reactor basin to deliver same quality as SBR. It has the ability to accomplish and deliver equalization, aeration, and clarification in respective. The special features of SBR makes it energy save, cost efficient, saving time, and low area space required. The SBR is operated aerobically to maintain the aerobic conditions for the ABT. Figure 6 shows SBR treatment in different stages.

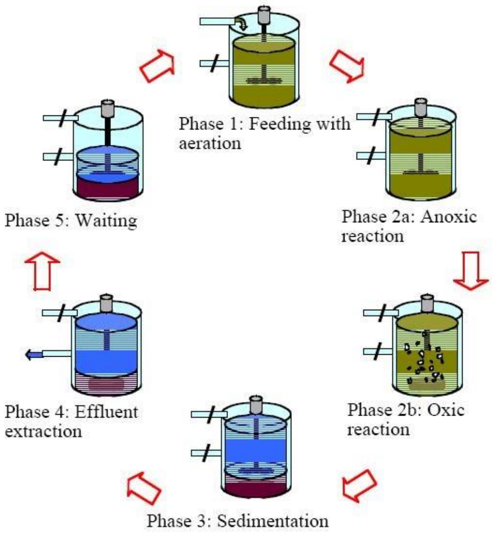


Figure 6. SBR process phases

There are five phases in SBR treatment for POME, starting with filling, reacting, settling, decanting, and idle. The operation is anoxic at the first stage. Mechanical ways are installed to provide sufficient mixing without air supply once influent enters the SBR. The mixed liquor aeration is consumed and used for reacting purpose at the 2nd stage. At the 3rd stage, mixing is completely shut off then the total suspended solids start to settle at the basin bottom. The clean treated liquor stream out as effluent from the basin during the 4th stage. Li et al. (2008) examined the effect of aeration activity on nutrients and organics from wastewater via two SBR in laboratory scale, for 8 hours at ambient temperature [27][28]. The wastewater concentrations were 350 mg/l of total nitrogen (TN), and 4000 mg/l of COD. The treatment efficiency increased with rising aeration amount. For example, COD, and TN removal performance achieved 90 and 34% respectively at 0.4 L/min of aeration rate, while COD, and TN achieved 97 and 95% of removal efficiency in respective at aeration rate 0.8 L/min. Kunda et al. (2013, 2014) tested SBR performance for COD, and TN subtraction [29][30]. It removed 95% of COD concentration for 8 hours SBR treatment and TN removal percent was ranging between 74.75 to 90.12%. Pan et al. (2014) evaluated SBR for removing TN, COD, and total phosphor (TP) at low temperature [31]. The removal performance was 98, 98, and 96% of TN, COD, and TP respectively. Finally, Pan (2014) conducted his experiment for 12 hours, and had found the optimum aeration rate and it was 0.6 L/min.

2.4 Biofilm Process

Biofilm can be defined as communities or matrix of microorganisms using extracellular polymer substance (EPS) to attach on a surface and start growing, developing, and building biofilm matrix [32][33]. Single or multispecies microbes can form and develop biofilm on biotic and abiotic surface [32]. Generally, the biofilm growth starts with bacteria attachment on surface, creation, maturation, and detachment [32][34]. Figure 7 presents the developing phases of biofilm bacteria.

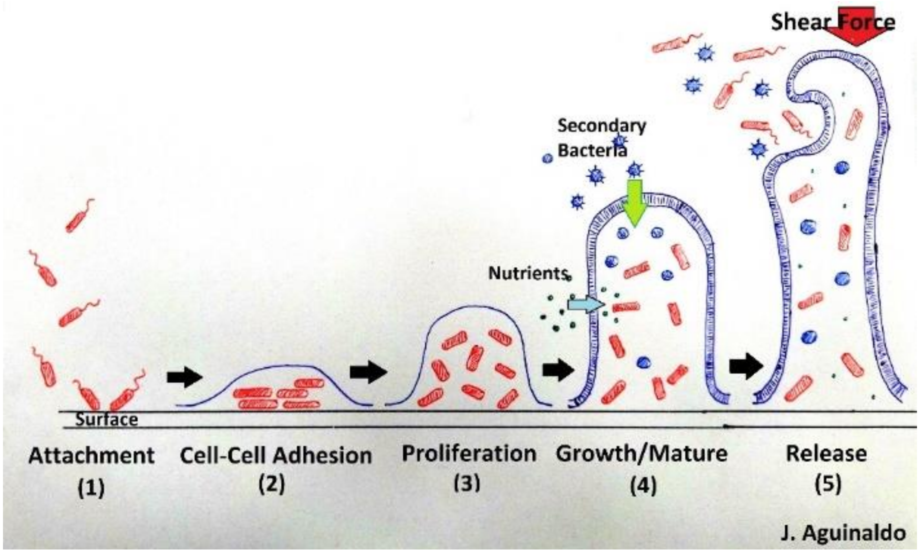


Figure 7. Biofilm development stages [32]

Each bacterium attempts to get closer as it can from another microorganism, or surface before it produces a transient attachment. This feature is a decent opportunity to adapt an appropriate place for their growth. Biofilm treatment has been used frequently for wastewater remediation and taking a place with physical and chemical processes due to their efficiency, and low treatment cost [35]. Biofilm is built to protect planktonic microorganisms and increase their survive chance from toxic and harsh circumstances. Biofilms provide a promising biotreatment for POME by requiring low operating conditions to break down nutrients. Besides, biodegradation and biosorption mechanisms of biofilm microorganisms remove dyes from POME [34]. However, unstable circumstances impact the biofilm process and leading to low quality effluent. It requires stable and optimized environmental conditions of pH range 6-8, and temperature range 25-40 ℃ to develop and grow [36]. Consequently, microorganisms in POME like Methanobacterium, Methanobrevibacter, Methanosarcina, Shewanella hydrolyzing, Ralstonia, Thermomonospora, and Actinomyces start producing methane gas. Most of it share many properties. Table 5 shows important parameters can impact biofilm growth.

Table 5. Circumstances effecting biofilm growth

Aspect	Outcome	Ref.
pH	Biofilm process can occur through pH range 3-10. The biodegradation process rapidly declines under strong acidic or strong alkaline conditions. The optimum pH range for biodegradation treatment is 7.	[36][37]
Temp.	The biodegradation process has the ability to rise to 50-70% at optimal temperature 37 ℃. A reduction in biodegradation process occurs due severe damage to microorganism cells at higher temperature or equal to 42 ℃.	[38][39]
Carbon and nitrogen	Biodegradation process could be shut off due unavailability of nutrients and carbon.	

Biofilm microorganisms decompose organic and inorganic matters of POME and convert it into soluble fine particles. Hence, it can be used as food source for microbes. Although, biofilm bacteria have various sorts of advantages, disadvantages, and limitations. Table 6 Shows these significant facts.

Table 6. Advantages, disadvantages, and limitations of Biofilm treatment

Advantages	Disadvantages	Limitations [40]
High quality of settling solids which doesn't require external separation or clarification stages [40].	Biofilm treatment needs long time to commence due to slow attachment process [40].	Startup time
High biofilm surface area [40].	Hard to control biofilm thickness [40].	Overgrowth
High biomass concentration [40].	Overgrowth of biofilm bacteria lead to elutriation process [40].	Thickness control
Small area required by using biofilm media (carriers) [40].	Large scale biofilm reactor requires expensive liquid distributors [40].	-
Reduction of excess sludge production [40].	-	-
Harmless and proficient biotreatment [41].	-	-
EPS reduces impacts of pH, toxic materials, and temperature to sustain the performance of biofilm process [42].	-	-

2.5 Microbial Fuel Cell (MFC)

Microbial fuel cell (MFC) system involves an oxidization process driven by microorganisms and performs an electrochemical feature at the anode side depending on the POME nutrients [42]. It produces electrons transported to the anode side, and protons transported to the cathode side. Besides, each single proton will be converted into water molecule. Frequently, a membrane is used to semi-isolate the anode from the cathode side [43]. Currently, researches have conducted to harvest the electrical energy from the MFC by using an external resister between the cathode and the anode, and it's still in their early stages. MFC system has disadvantages as well as many POME biotreatments, such as low energy production, and high materials cost. Recent papers have been published discussing and conducting various empirical work on wastewater for electricity generation [44][45][46][47]. There are many materials have been used to build high quality electrodes, such as carbon felt, carbon paper, carbon cloth, graphite fiber brush, and graphite rod but majority of anode materials are fabricated from carbon which has high resistivity [48][49][50]. Cu TiO2, Ni, and Si can be used as edges metal for resistivity minimization purpose. Besides, if resistivity became eliminated, power can be optimized from MFC. Major circumstances control MFC performance like proton mass transfer rate to the cathode, electrons transfer rate to the anode, bacteria type, electrode material and quality, and biodegradation stability [51].

The biofilm bacteria in POME attach on the electrode surface to transfer electrons. MFC utilizes wastewater microbes as biocatalyst to produce electricity from chemical energy in organic materials [52][53]. Since POME is highly polluted which could be indicated from high ranges of COD and BOD is appropriate to be used as an influent for the MFC. Previously, POME had been used as substrate in double chamber MFC, it produced 45 mW/m^2 of energy and 45% removal of COD concentration within 15 days [54]. In another research, POME MFC had produced 622 mW/m^2 of electricity, while, it generated 3004 mW/m^2 of electricity by using water contains acetate [55]. In below, Table 7 shows various advantages, disadvantages, and limitations on MFC process.

Table 7. MFC advantages, disadvantages, and limitations

Advantages [56]	Disadvantages	Limitations [57]
High energy conversion	Require expensive electrodes	Limited electricity generation
Efficient process at ambient temperature	MFC still in their initial stages	Clog
Aeration isn't required in the MFC reactor, that would make it energy efficient	Producing Low electricity	Electrodes resistance
Treating and generating energy in one time	MFC system is not ready to be scaled up	
	Membrane fouling	

2.6 *Bio Towers*

Bio towers or trickling filters are comprised of media layer in a tank with fixed nozzles. Bio towers require pre-treated influent from oil and coarse. Hence, rotary distributors are occasionally used instead of fixed nozzles to spray pretreated wastewater over the media surface to filter the wastewater. Air feed flows from down to upside passing through the media layer [18]. The continuous streaming of air feed delivers good interaction between nutrients and microorganisms and achieves biodegradation. Then, a cream layer highly contaminated of nutrients is created on the surface and gets denser by time. Finally, it starts to settle and reducing the medium contamination level. Unfortunately, bio towers are expected to act less performance in terms COD and BOD removal than other ABT. Figure 8 presents bio towers for wastewater treatment.

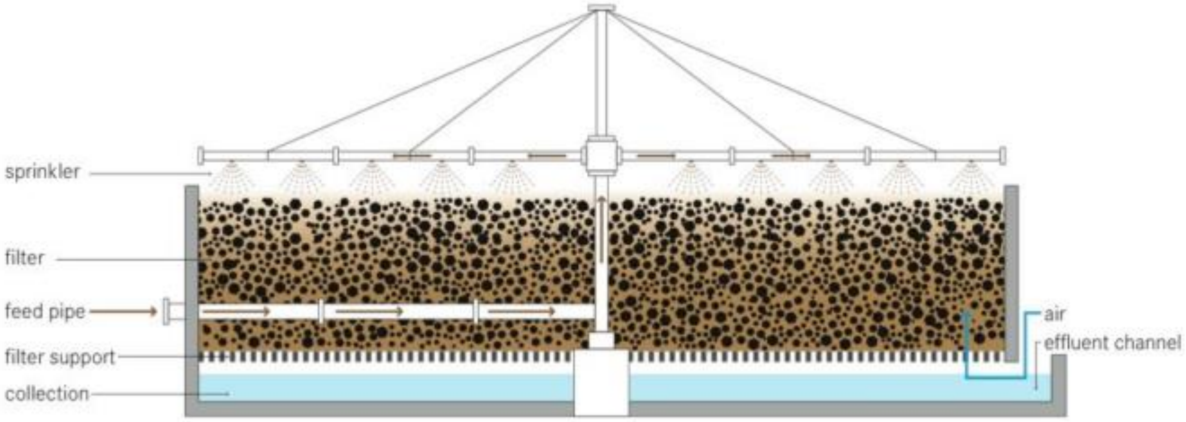


Figure 8. Bio tower

Bio tower can be defined as a group of mechanical and biological processes for wastewater. It has the ability to remove algae by using trickling filter, which leads to BOD, total suspended solids (TSS), and COD reduction. It can remove 80% or higher of TSS, and BOD concentrations [58][59]. Table 8 presents many important advantages, and disadvantages that should be considered for POME treatment by using bio tower.

Table 8. Bio tower advantages, and disadvantages for POME treatment [60][61]

Advantages	Disadvantages
Good capability to remove any type of contaminants	High pressure drops
Doesn’t require inoculation process	Issues with processing acidic gases
Simple	
Low cost	

2.7 *Rotating Biological Contactors (RBC)*

RBC is comprised of vertically arranged plastic media on a horizontal rotating shaft for biomass attachment and growth. RBC allows microorganisms to attach on the media surface, and while the media is rotating, the microorganisms metabolize and absorb numerous of organic matters and nutrients by the provided interaction from RBC process [12]. The attached biomass on the surfaces are exposed to atmosphere and wastewater as the shaft rotates in speed 1 to 1.5 rpm, and the percentage of submerged media is 40% [18]. However, RBC process isn’t highly efficient to process wastewater than many different methods such as conventional aerobic system [62][63]. The capability of RBC is ranging between 40 to 85% of COD removal. It’s worth mentioning that surface area of the plastic media is an important factor that can bring stability and high growth rate to mature. Figure 9 shows RBC structure and its process.

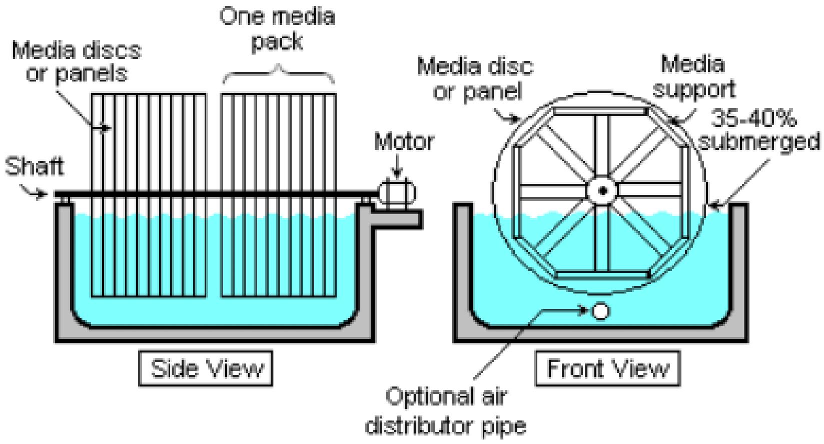


Figure 9. Rotating biological contactors schematic diagram

2.8 *Aerobic Granulation Technology (AGT)*

AGT provides self-immobilization for microorganisms to biodegrade nutrients and producing bio sludge which is called granular sludge without the use of biofilm carriers [64]. AGT is considered the outcome of numerous investigations that occurred on biofilm treatment at the late 1990s [65]. The bio granulation process of AGT is consisted of feeding, reacting, settling, and decanting [66]. AGT starts by the self-adhesive microbes, and they are expected to not start combining with other type of microorganisms [67]. Figure 10 illustrates the AGT mechanism.

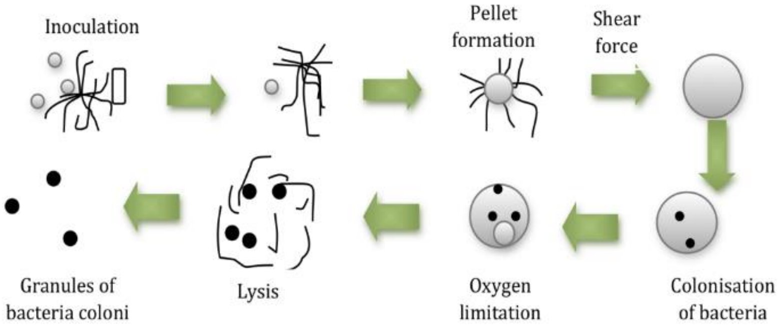


Figure 10. Scheme of aerobic granulation process

The bio granulation process commences with fungi and filamentous microorganisms which easily produce mycelial pellets. These pellets retain and settle in the reactor. Bacteria don't have this special process, and it gets washout. The microorganisms de-attach from the mycelial pellets due the shear force. These pellets grow and get denser for about 5 to 6 mm diameter, after that they go for degradation process because of oxygen lack in the reactor. The bacteria attach on the mycelial pellets, and start to grow, and develop to make colonies, for that this colony settle at the reactor bottom. This process allows the bacteria to grow, increase their population, and get denser [68][69]. There are many important benefits from using AGT, such as removal of phosphate and nitrogen, COD and toxicity reduction, ability to process high organic load, strong microbial matrix, and excellent settling process [70][71][72]. The bio granulation of POME takes 60 days with 2.5 kg COD m^{-3}/day of organic load. It can reduce 66% of color, 89.3 to 97.6% of ammonia, and 85 to 95% of COD concentration [73]. Some researchers reported several disadvantages about AGT efficiency, such as instability and slow growing process [73].

A lot of researchers have worked on various aerobic bioprocesses for different kinds of wastewater, for that, a summary of researches was tabulated in Table 9 to show effectiveness, performance, and capability of wastewater bioremediation.

Table 9. Latest researches on wastewater treatment methods

Technology	Wastewater	Characteristics (mg/l)	Results (mg/l)	Ref.
SBR	Olive mill wastewater	-	90% and 60% for COD and total polyphenols concentration (TPPs), respectively.	[74]
Plug flow microbial fuel cell	Connecticut University wastewater plant	-	70±13% of COD removal	[75]
Complete mixing microbial fuel cell	Connecticut University wastewater plant	-	81±09% of COD removal	[75]
Sequencing batch biofilm reactor combined with vertical flow constructed wetland	Domestic wastewater	200.22 of COD, 48.11 of $NH4^{+}$-N, 48.11 of TN and 6.11 of TP	97.0% of COD, 98.5% of $NH4^{+}$-N, 91.5% of TN and 88.5% of TP	[76]
SBR	Urban wastewater	-	83% of soluble chemical oxygen demand (SCOD), 60% of $N–NH_4^+$, 70% of TSS and 80% of volatile suspended solids (VSS)	[77]
Aerobic sludge granulation	Domestic wastewater	-	98.17% of COD, 94.45% of ammonia, and 72.46% of phosphate removal	[78]
RBC	Agrochemical wastewater	-	78% of total organic carbon (TOC), and 50% of TN	[79]
A cubic lattice based RBC	A milk factory and a hospital wastewaters	-	60-90% of COD	[80]
Constructed Wetlands	Lahore city wastewater	-	90% of TSS, 75% of BOD and 80% of COD at 5 days	[81]
Stabilization ponds	oil refinery wastewater	-	71.9–91.2% of SCOD, 76.4–93.3% of TCOD, 68.4-91.7% of soluble Biochemical Oxygen Demand (SBOD), 75.9 – 93.7% of total Biochemical Oxygen Demand (TBOD) and 77.6 – 98.0% of phenol	[82]
RBC	Antibiotic Pharmaceutical Wastewater	-	45% of COD, 40% of NH^{+}_{4}-N, and 85% of BOD5	[83]
A Two-Stage Microbial Fuel Cell and Anaerobic Fluidized Bed Membrane Bioreactor	Domestic Wastewater	Total chemical oxygen demand (TCOD) is about 210±11	92.5% of TCOD, nearly complete removal of TSS, 50 days, and 25 °C of room temperature	[84]

3 Conclusion and Future Trends

Palm oil industries of Malaysia are seeking sustainable methods for palm oil production. There are a lot of motivated and intensive researches occurring on POME polishing. The future technology of POME processing should be skilled enough to accomplish POME recovery, reuse, and zero contamination. The reviewed technologies ABT can deliver the expected discharge limitation 20 mg/l of BOD3. Majority of POME polishing processes don’t accomplish the promising quality due to unexpected impact, or instability, which leads to unsatisfactory excellence.

This review had shown ABTs that are possible to be use as polishing processes for POME. All the presented ABTs have uncontrollable limitations and drawbacks. Therefore, this review finds developing a hybrid system comprised from a number of ABTs can defeat number of limitations and improve effluent quality. It can be placed as an important part of treating POME, because it’s a promising system. Moreover, the selection of a hybrid system is vital because it should be based on the influent quality, such as COD, BOD, TSS, SS, TN, and TP. To our best of research, and knowledge, there is no single sustainable technology at the present to process POME. Hence, scientists are working intensively to present a promising method that can achieve astonishing efficacy and secure waterways from the industrial discharges.

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