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A Review of Biofilm Treatment Systems in Treating Downstream Palm Oil Mill Effluent (POME)

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Abstract: The palm oil industry is a vital economic backbone of Malaysia since it is one of the world's largest producer and exporter of palm oil despite creating enormous environmental problems, one being the huge generation of Palm Oil Mill Effluent (POME) during the oil extraction process. This highly polluting wastewater contains high concentrations of Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). Due to the high organic content of POME, biological treatment method seems to be a preferable solution. Therefore, a series of treatment comprising of fermentation, algae, biofilm and membrane system is proposed as one of the possible option to treat POME. This paper also reviews few configurations and modes of operation of several biofilm treatment systems as well as focusing on the application of a Fluidized Bed Biofilm Reactor (FBBR) in treating POME further down the proposed treatment chain.

Key words: Wastewater, palm oil mill effluent, biofilm

INTRODUCTION

Malaysia is one of the world's largest producer and exporter of palm oil. According to the Malaysian Palm Oil Council (MPOC), approximately 16,000 and 17,000 tonnes of Crude Palm Oil (CPO) were produced in 2008 and 2009, respectively (MPOC, 2011). Even with the high amount of profit gained to the nation, a huge amount of highly polluting wastewater; Palm Oil Mill Effluent (POME) is generated during the oil extraction processes. This contributes to an enormous pollution problem hence questioning the sustainability of the palm oil industry itself. POME is a non-toxic thick brownish liquid waste, which has an unpleasant odour. It contains high amounts of total solids, oil and grease, with high concentrations of COD and BOD. Table 1 summarises the characteristics of POME as well as the standard discharge limit of effluent into water streams.

Table 1: Raw POME characteristics and regulatory effluent discharge limits (DEM, 2011)

Parameter	Average value*	Standard discharge limits*
Temperature	85	-
COD	50000	100
BOD_5**	25000	50
pH	4.7	5.5-9.0
Oil and grease	4000	100
Total solids	40500	-
Suspended solids	18000	400
Total volatile solids	34000	-
Ammonical nitrogen	35	-
Total nitrogen	750	150
Phosphorus	180	-
Potassium	2270	-
Magnesium	615	-
Calcium	439	-
Boron	7.6	-
Iron	46.5	50
Manganese	2	10
Copper	0.9	10
Zinc	2.3	10

*All values are in mg L^{-1} except for temperature, which is in °C and pH, **The sample for BOD analysis is incubated at 30°C for 5 days

According to Borja and Banks (1994), 2.5-3.0 tonne of POME is produced during the extraction process for every tonne of crude oil obtained. Since the production of CPO for the past few years kept on increasing from year to year, the amount of POME generated is almost 3 times higher. This ultimately leads to an urgent need of finding methods of treating POME in the palm oil industry. Currently, the conventional treatments of POME are for instance, anaerobic digestion and extended aeration, which only leads to more severe pollution problem. This is due to large amount of greenhouse gases (i.e., methane and carbon dioxide) released into the atmosphere (Wu *et al*., 2010). Therefore, finding a sustainable, clean and pollution free solution is an urgent matter for the palm oil industry to maintain its environmental sustainability.

A sustainable solution can be developed by implementing a 'waste to wealth' approach that follows

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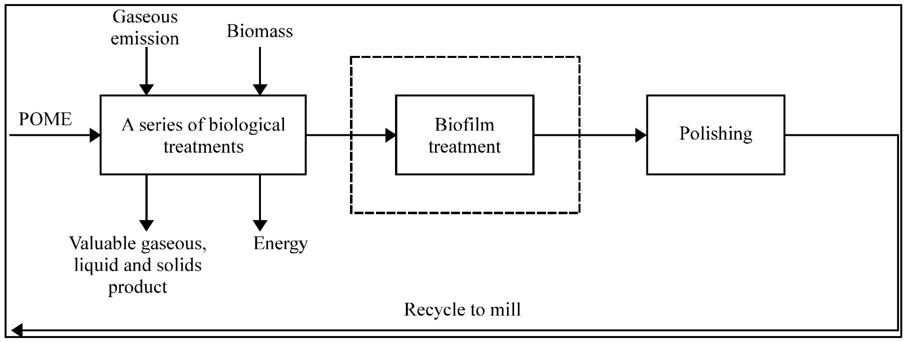

Fig. 1: Proposed treatment scheme for POME

the 5R strategies; Reduction, Replacement, Reuse, Recovery and Recycling. The proposed treatment scheme based on this approach (Fig. 1) comprises of a sequence of treatments commencing with a series of biological treatments inclusive of fermentation and algae systems, followed by a downstream POME treatment by a biofilm system and completed by undergoing a polishing stage, which in this case is a membrane system. Raw POME undergoes biological treatments that release valuable by-products as well as energy, which can then be used in the reactors operation. The treated POME then undergoes biofilm treatment to further reduce the COD and BOD contents to reach the acceptable discharge limit standards. Finally a polishing stage is required to further enhance the quality of the effluent thus making it suitable for recycle and used back in the palm oil mill.

BIOFILM SYSTEM

Definition, structure and characteristics: In natural environments, majority of microorganisms attach to a moist surface and therefore exists as biofilms. By definition, biofilm is a complex structured community of bacterial cells that are densely packed together in a self-enclosed slimy polymeric matrix that adhere to a surface or interface (Wood *et al*., 2011). Due to the constantly changing microenvironments that are experienced by the microbial cells in biofilms, it is very hard to generalize the structure and physiological activities of biofilms. However, there are common characteristics that all biofilms exhibit. For instance, they can attach on any surface ranging from metals to plastics and can be found in a vast range of natural and artificial environments (Van Houdt and Michiels, 2005). Biofilm structures are very complex and will significantly vary depending on several factors. These factors include the microbial cells present, their physiological and physical conditions as well as available nutrients in the environment that will all determine the structural integrity of the biofilm (Lazarova and Manem, 1995). However, the main component that holds the structure together is the extracellular polymeric products (EPS). Majority of biofilms are composed of up to 97% of water even though this might not always be the case. Generally, the biofilm matrix consists of secreted polymers, absorbed nutrients and metabolites as well as particulate material and detritus from the immediate surroundings (Sutherland, 2001).

One of the most important characteristics of biofilm is that the behaviours and microbial activities of a biofilm consisting of various populations of bacterial cells are not possible by any of the individual component species (Li *et al*., 2009; Simoes *et al*., 2010). This is proven by a study conducted by Chae and Schraft (2000) that investigated the growth behaviour of *Listeria* in biofilms. They found out that the growth behaviour was different between the cells in biofilms and their planktonic (free swimming) growth. Besides that, biofilm bacteria are more resistant towards antimicrobial agents and other environmental stresses when compared to planktonic bacteria. This is due to the existence of a strong EPS matrix that protects the microbial cells within the biofilm (Sutherland, 2001). This matrix however is greatly affected by the environment's hydrodynamic conditions as well as the shear rate and flow velocity.

Why a downstream biofilm system?: Since biofilms can be used for bioremediation, it is also suitable for treating POME which consists mainly of organic contents and solids. However, due to the high concentration of COD and BOD in POME (Table 1), pre-treatment steps need to be taken prior POME treatment via the biofilm system. Otherwise, clogging of biofilm pores as well as high organic loading rate into system might happen. There are numerous pre-treatment steps that can be considered which include anaerobic/aerobic fermentation, membrane separation processes and many more. As what has been mentioned in the proposed treatment scheme, raw POME initially undergoes fermentation and algae treatment systems. When a suitable concentration of the POME constituents is reached, biofilm system can therefore be applied to the pre-treated POME.

In a biofilm system, microorganisms decompose harmful compounds of wastewater using enzymes (Morikawa, 2006). They live on those compounds as their nutrient source and continue to grow leading to thicker biofilms attached to the surface of reactor. Biofilm activity increases with the thickness of biofilm until the 'active thickness' is reached. Above this level is where the diffusion of nutrients becomes a limiting factor and biofilm is then 'inactive'. A stable, thin and active biofilm thus offers numerous advantages in POME and other wastewater treatments (Lazarova and Manem, 1995).

To date, majority of biofilm reactors favours to operate under anaerobic conditions rather than aerobic condition to optimize quick growth and regular operation of an active biofilm. Due to the development of biofilm reactors, treating wastewaters via anaerobic treatment becomes an attractive option. There are a few factors that should be taken into account to optimize the design and scale up of these biofilm reactors. These consist of (1) The effect of hydrodynamics or flow pattern on reactor performance, (2) Mass transfer within granules, (3) Kinetic effects and (4) Structure and composition of biogranules (Saravanan and Sreekrishnan, 2006). Elaborated discussions on these parameters are presented by Saravanan and Sreekrishnan (2006) in their review paper.

Basically, for a technically feasible and sustainable biofilm reactor operation, the reactor has to be operated in a way that optimizes the start-up period and regular operation of biofilm. These both can be achieved by a quick growth of an active biofilm during the start up phase and regular maintenance on the attached biofilm as to avoid diffusion limitations and clogging (Escudie *et al*., 2011).

APPLICATIONS OF BIOFILM SYSTEM IN TREATING POME

There are two general classes of biofilm reactors; fixed bed and particulate bed biofilm reactors. These two systems vary in their characteristics and mode of operation as described below.

Fixed biofilm reactors: A fixed biofilm reactor is mostly suitable for wastewater containing high biomass concentrations that requires efficient anaerobic treatment. It contains a fixed/immobilized inert medium or carrier which is added into the reactor vessel thus operated to favour the growth of microorganisms attached to the media surface (Hall, 1987). In the operation of this reactor, the start-up phase plays an important role in determining the process is feasible or otherwise. During start-up, development of an active biofilm on the carrier until the nominal Organic Loading Rate (OLR) is reached takes place. To ensure successful start-up of reactor, it is important to take note of the following key factors. Firstly, only a short time of contact between inoculums and the carrier material is necessary to obtain adhesion of microorganism and initiate biofilm formation. Secondly, a short Hydraulic Retention Time (HRT) is required to wash out suspended biomass from the reactor and thus forcing biofilm growth on the carrier material (Hall, 1987).

Particulate biofilm reactors: This type of biofilm reactors are the most widely used in comparison with fixed biofilm reactor and membrane aerated biofilm reactor. There are various types of particulate biofilm reactors such as Upflow Sludge Blanket (USB), Biofilm Fluidized Bed (BFB), Expanded Granular Sludge Blanket (EGSB), Biofilm Airlift Suspension (BAS) and internal circulation reactors (Nicolella *et al*., 2000). The mode of operation of these reactors are almost similar to each other as biofilms contained in the reactors are not fixed, but exists as microaggregates that are free to mobilize. In this type of reactor, the efficiency mainly depends on active biomass concentration and the influent flow rate (Saravanan and Sreekrishnan, 2006; Mosquera-Corral *et al*., 2003).

To ensure maximum reactor performance, the reactor start-up phase must be optimized similar to that stated in the previous section. However, for a particulate biofilm reactor, low fluidization velocity should be applied to allow faster accumulation of biomass fixed on the carrier. One major problem associated with this type of reactor is the modification of the carriers. During reactor operation, the biofilm thickness will keep increasing on the carrier surface and cause enlargement of the particle's diameter. In addition, the shape and surface roughness of the particles also changes. Therefore, implementation of external separators, internal screen cleaning devices, operation of an impeller at the top of the bed should be implemented to control the biofilm properties. Besides, successful control of the biofilm thickness also helps to prevent particle segregation and wash out (Escudie *et al*., 2011). The Table 2 summarizes the advantages and disadvantages of the application of particulate biofilm reactors.

Future studies: The Fluidized Bed Biofilm Reactor (FBBR), which is a type of a particulate biofilm reactor, has high potential to be applied in the industry. This is

Table 2: Advantages and disadvantages of particulate biofilm reactors

Advantages	Disadvantages
High terminal settling velocity of solids, leading to possible elimination of external clarification/separation stages	Biofilm formation on carriers poses problem leading to long start-up times
High reactor concentration	Control of biofilm thickness is difficult
High biofilm surface area	Overgrowth of biofilms leads to elutriation of particles
High biomass concentration and mass transfer area result in high conversion capacities	Liquid distributors for fluidized systems are costly for large-scale reactors and pose problems with respect to clogging and uniform fluidization
Compact reactor with small area requirements	
High biomass age and minimization of excess sludge production	

Adapted from Nicolella *et al.* (2000)

due to many factors such as the organic loading from the series of biological treatment is within suitable range for FBBR application. Not only that, the high organic removal rate of more than 95% eases the load on the polishing stage, which is highly preferable. However, there are also challenges that tend to limit the application of the system. This includes the need to handle a large amount of POME that is generated during the oil extraction process, which also means a high organic loading into the FBBR. Therefore it is necessary to maintain optimum operating conditions to ensure maximum reactor performance.

Prior to FBBR operation, the biofilm inside the reactor first needs to be grown on an appropriate surface. POME sludge from aerobic ponds are used as seed microbes and cultured in a Sequencing Batch Reactor (SBR) before being transferred to the FBBR. Parameters of COD, BOD_5, TOC, pH, DO, ORP, total nitrogen, total phosphorus, colour and turbidity needs to be monitored during the FBBR operation to analyze the efficiency of the treatment system in treating downstream POME.

Other examples of reactors that have high potential for sustainable treatment systems are Biological Aerated Filter (BAF), Upflow Anaerobic Sludge Blanket (UASB), Granulated Activated Carbon-SBR and Integrated Membrane Bioreactor.

CONCLUSION

Since the palm oil industry is one of the most important industries in Malaysia, its sustainability is a vital issue to be concerned of. Therefore, the huge production of POME must be treated prior to discharge into water streams. There are various treatment methods that have been studied and one promising method is the application of a biofilm system. Biofilm is a potentially viable treatment system to further enhances the quality of the effluent. However, the biofilm structure is very complex and complicated in nature, thus careful consideration on the design parameters for the system should be taken into account. Two common types of biofilm reactors are the fixed biofilm reactor and particulate biofilm reactor. The latter is widely used in comparison with the former due to its several advantages. Experimental tests involving various biofilm systems are required to determine the most suitable design and scale up of such reactors to ensure successful operation of a biofilm reactor in treating POME.

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REFERENCES

Borja, R. and C.J. Banks, 1994. Treatment of palm oil mill effluent by upflow anaerobic filtration. J. Chem. Technol. Biotechnol., 61: 103-109.

Chae, M.S. and H. Schraft, 2000. Comparative evaluation of adhesion and biofilm formation of different *Listeria monocytogenes* strains. Int. J. Food Microbiol., 62: 103-111.

DEM, 2011. Malaysia sewage and industrial effluent discharge standards. Department of Environment of Malaysia, Malaysia.

Escudie, R., R. Cresson, J.P. Delgenes and N. Bernet, 2011. Control of start-up and operation of anaerobic biofilm reactors: An overview of 15 years of research. Water Res., 45: 1-10.

Hall, E.R., 1987. Biofilm reactors in anaerobic wastewater treatment. Biotechnol. Adv., 5: 257-269.

Lazarova, V. and J. Manem, 1995. Biofilm characterization and activity analysis in water and wastewater treatment. Water Res., 29: 2227-2245.

Li, M.Y., J. Zhang, P. Lu, J.L. Xu and S.P. Li, 2009. Evaluation of biological characteristics of bacteria contributing to biofilm formation. Pedosphere, 19: 554-561.

MPOC, 2011. Oil palm plantation and Malaysian palm oil industry. Malaysian Palm Oil Council, Malaysia.

Morikawa, M., 2006. Beneficial biofilm formation by industrial bacteria *Bacillus subtilis* and related species. J. Biosci. Bioeng., 101: 1-8.

Mosquera-Corral, A., A. Montras, J.J. Heijnen and M.C.M. Van Loosdrecht, 2003. Degradation of polymers in a biofilm airlift suspension reactor. Water Res., 37: 485-492.

Nicolella, C., M.C.M. Van Loosdrecht and J.J. Heijnen, 2000. Wastewater treatment with particulate biofilm reactors. J. Biotechnol., 80: 1-33.

Saravanan, V. and T.R. Sreekrishnan, 2006. Modelling anaerobic biofilm reactors: A review. J. Environ. Manage., 81: 1-18.

Simoes, M., L.C. Simoes and M.J. Vieira, 2010. A review of current and emergent biofilm control strategies. LWT- Food Sci. Technol., 43: 573-583.

Sutherland, I.W., 2001. The biofilm matrix-an immobilized but dynamic microbial environment. Trends Microbiol., 9: 222-227.

Van Houdt, R. and C.W. Michiels, 2005. Role of bacterial cell surface structures in *Escherichia coli* biofilm formation. Res. Microbiol., 156: 626-633.

Wood, T.K., S.H. Hong and Q. Ma, 2011. Engineering biofilm formation and dispersal. Trends Biotechnol., 29: 87-94.

Wu, T.Y., A.W. Mohammad, J.M. Jahim and N. Anuar, 2010. Pollution control technologies for the treatment of palm oil mill effluent (POME) through end-of-pipe processes. J. Environ. Manage., 91: 1467-1490.