Bioresource Technology 245 (2017) 916–924

Contents lists available at ScienceDirect

Bioresource Technology

journal homepage: www.elsevier.com/locate/biortech

Treatment of palm oil mill effluent using combination system of microbial fuel cell and anaerobic membrane bioreactor

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ARTICLE INFO

Keywords:
Anaerobic membrane bioreactor
Microbial fuel cell
Operational temperature

ABSTRACT

It was found that the operational temperature and the incorporation of microbial fuel cell (MFC) into anaerobic membrane bioreactor (AnMBR) have significant effect on AnMBRs' filtration performance. This paper addresses two issues (i) effect of temperature on AnMBR; and (ii) effect of MFC on AnMBRs' performance. The highest COD removal efficiency was observed in mesophilic condition (45 °C). It was observed that the bioreactors operated at 45 °C had the highest filtration resistance compared to others, albeit the excellent performance in removing the organic pollutant. Next, MFC was combined with AnMBR where the MFC acted as a pre-treatment unit prior to AnMBR and it was fed directly with palm oil mill effluent (POME). The supernatant from MFC was further treated by AnMBR. Noticeable improvement in filtration performance was observed in the combined system. Decrease in polysaccharide amount was observed in combined system which in turn suggested that the better filtration performance.

1. Introduction

Oil palm is a perennial and valuable crop that grows in the tropical regions of the world like Indonesia and Malaysia, with hot and humid climate throughout the year and the production continues throughout the year (Garcia-Nunez et al., 2016). Its product, palm oil is cheap, production-efficient and highly stable oil that are widely used in a variety of foods, cosmetic, hygiene products and even potentially to be used as a source for biofuel, rendering palm oil to be one of the worlds's most produced and consumed oils (Indonesia-Investments, 2016). In Malaysia, extraction of crude palm oil from fresh fruit bunches is mainly through wet palm oil milling process. The milling process involves consumption of enormous quantities of water and is typically obtained from the adjacent freshwater resources which require very little treatment and pumping costs. The concomitant large production of wastewater from milling processes mainly comprises of palm oil mill effluent (POME) and used water. The used water is discharged into the drains or rivers without going neither into the effluent stream nor the wastewater treatment system. While POME, being one of the major pollution sources to water bodies require proper treatment prior to its disposal in order to meet the imposed discharge limit (Liew et al., 2015).

MBR system is one of the promising methods which involve the combination of biological treatment with the aids of activated sludge coupling with a direct solid-liquid separation by membrane filtration. In membrane filtration process, microfiltration or ultrafiltration membrane technology are used to completely retain the bacterial flocs and nearly all suspended solids within the bioreactor (Le-Clech et al., 2006). This renders the quality of water produced to be significantly higher than that generated by conventional treatment and excluding the necessity of having a further tertiary treatment (Judd, 2008). By filtering the biomass through the membrane, the MBR technology not only effectively producing a high quality effluent but also shows substantial disinfection capability in the effluent produced as it removes all suspended, colloidal solids and bacteria including attached viruses or adsorbed compounds (Nguyen et al., 2016; Hoek and Tarabara, 2013; Santos et al., 2011). Besides that, the MBR process capable of operating at much higher mixed liquor suspended solids (MLSS) concentrations (about 12,000 mg/L) such that higher volumetric loads are feasible, thereby giving rise to a small footprint (Trzcinski and Stuckey, 2016; Hoek and Tarabara, 2013). Moreover, the MBR system requires less area compared to conventional activated sludge process (Nguyen et al., 2016). The conventional activated sludge process which comprises of activated sludge tank and settling tank are combined in the MBR system where the settling tank is replaced by membrane, rejecting the activated sludge from passing through the membrane and the

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http://dx.doi.org/10.1016/j.biortech.2017.08.202
Received 6 July 2017; Received in revised form 24 August 2017; Accepted 30 August 2017
Available online 01 September 2017
0960-8524/

sedimentation process is substituted by filtration process (Hoek and Tarabara, 2013). Such combination also results in higher concentration of activated sludge in the bioreactor and lower amount of wasted biosolids is produced (Le-Clech et al., 2005). The MBR system can be divided into aerobic and anaerobic process. In anaerobic MBR system, methane produced from the digestion process can be recovered and used as a renewable energy, rendering it to be an interesting option for POME treatment (Poh and Chong, 2009).

Despite the fact that MBR system features various advantages such as higher organic removal efficiency, reduction in footprint and sludge production; still, membrane fouling remains as the perennial and primary challenge to deal with and limits the wide application of MBR technology (Hong et al., 2016).

Membrane fouling is resulted from interactions between foulants and membrane. The occurrence of membrane fouling is characterized by decreasing permeate flux or increasing transmembrane pressure and followed by decrease in membrane performance. In order to maintain the function of the membrane, frequent membrane cleaning is required which subsequently increase the energy consumption and deteriorate the membrane lifespan. Hence, this becomes a critical factor affecting the economic and technological viability of the processes (Cordova et al., 2016; Martin-Pascual et al., 2016). The major factors affecting fouling are biochemical kinetic parameters, temperature, membrane characteristics, mixed liquor characteristics, operational style and reactor hydraulic conditions. Therefore, membrane fouling mechanisms are very complicated due to the complex rheological and physiological characteristics of mixed liquors (Martin-Pascual et al., 2016).

In MBR which involves the anaerobic digestion, temperature exerts a significant role on the performance and stability of the process. The operational temperature can be classified into three regimes which are psychrophilic (lower than 20 °C), mesophilic (30–45 °C) and thermophilic (55–65 °C) temperature (Lin et al., 2009). The good operational performance in mesophilic temperature renders it to be widely adopted for anaerobic digestion, whereas the use of thermophilic regime is less extensive because it is highly susceptible to environmental changes and thus poorer process stability. Despite the application of thermophilic anaerobic digestion is limited, it is known to present several advantages such as an increased destruction rate of organic solids and elimination of pathogen (Meabe et al., 2013; Lin et al., 2009). The biomass growth rate of microbial community is heavily dependent on the operational temperature, for instance, relatively lower operational temperatures tend to reduce the biomass growth rate (Martinez-Sosa et al., 2011). Besides, increase in temperature could significantly enhance the filtration performance (Meabe et al., 2013). However, fouling propensity is higher in thermophilic temperature due to the higher production of soluble microbial products (SMP) and extracellular polymeric substances (EPS) and the significant decrease in sludge floc size in thermophilic temperature under long-term operation is responsible for increased filtration resistance (Lin et al., 2009).

Other than MBR, microbial fuel cell (MFC) is also a promising technology with the capability of recovering energy and treating wastewater. There is increased interest among the academic researchers in the last decades (Tian et al., 2015; Karmakar et al., 2010). MFC utilizes the presence of electrochemically-active microorganisms as catalysts, oxidizing then converting the chemical energy stored in the organic matter in the wastewater into useful electrical energy while treating the wastewater (Ma et al., 2016; Su et al., 2013; Karmakar et al., 2010). The increasingly emerging and widespread application of MFC in wastewater treatment is largely due to its outstanding merits. The capability of MFC in converting the substrate energy to electricity directly, rendering it to be more sustainable when come to implementation in wastewater treatment. Besides that, less excess activated sludge is generated compared to the processes of anaerobic digestion and conventional aerobic activated sludge treatment systems. Moreover, the insensitivity of MFC to operation environment renders it to be more viable. The necessity of having gas treatment and the need for aeration can be opted out, and hence reducing the energy input (He et al., 2017). Despite the numerous advantages of MFC, some of the challenges remain unaddressed which subsequently hinder the commercialization of MFC technology. One of the barriers is the MFC, as an independent wastewater treatment unit will not be practically applicable due to its poor effluent quality and low treatment efficiency (Tian et al., 2015). According to Kim et al. (2016), the power densities are corresponding to the COD concentrations of wastewater. Therefore, it is unlikely to achieve high power densities while meeting the stringent discharge limit of the wastewater to the environment. In order to overcome this issue, a post-treatment process is necessary to further reduce the COD of the treated effluent from MFC.

In order to meet the stringent effluent quality, wastewater treatment solely by MFC is insufficient (Tian et al., 2015). Thus, MFC is integrated with other systems such as MBR. The integration of MBR with MFC forms a bioelectrochemical membrane reactor, which takes advantage of both MBR and MFC, enhancing the effluent quality while achieving energy recovery (Su et al., 2013). In fact, membrane technology is widely implemented and has excellent filtering capability in removing all suspended, colloidal solids and bacteria including attached viruses or adsorbed compounds (Nguyen et al., 2016; Hoek and Tarabara, 2013; Santos et al., 2011). According to Su et al. (2013), the combined system of MBR and MFC was able to mitigate the membrane fouling through the modification of sludge. It was found that the combined system could operate twice as long as that in the conventional MBR. Furthermore, the report showed that the MFC could effectively reduce the loosely bound extracellular polymeric substances (LB-EPS) content by 22%. Such EPS are considered to be the major cause of membrane fouling in MBR. By integrating the MBR with MFC, it has the benefits to improve the effluent quality, recover energy produced and mitigate the membrane fouling. Therefore, instead of using MBR as sole treatment process, MBR can incorporate with technology like microbial fuel cell (MFC) to reduce the fouling propensity. Such integrated system achieves higher effluent quality and more efficient energy recovery. Several studies showed that the integrated system improved the membrane filterability by retarding membrane fouling by using synthetic wastewater as the feedstock (Tian et al., 2015; Su et al., 2013). However, the use of combined system in treating high strength wastewater like POME is yet to be studied.

Hence in this study, MFC is incorporated into the AnMBR system (MFC-AnMBR) where the MFC acts as a pre-treatment unit prior to AnMBR and one of the operational conditions, temperature is manipulated and their impact on the degree of membrane fouling is observed.

2. Materials and method

2.1. Materials

2.1.1. Powdered activated carbon (PAC)

The PAC used in this study is extra pure Charcoal Powdered Activated Carbon supplied by Gene Chem. The general specification of the PAC is illustrated in Table 1(a).

2.1.2. Palm oil mill effluent (POME)

The POME with general characteristics as per Table 1(b), a high strength industrial wastewater was treated by using it as the feed to the AnMBR system. It was supplied by Tian Siang Holdings Sdn Bhd which is located in Air Kuning, Perak. A filtered sieve with mesh size of 0.053 mm (No. 270) was used to filter the POME feedstock prior to feeding into the system.

2.2. Operation of MFC and AnMBRs

One single chamber and air cathode MFC with a volume of 1 L was constructed. In single chamber MFC, one side of the cathode layer was