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Membrane fouling behavior in anaerobic baffled membrane bioreactor under static operating condition

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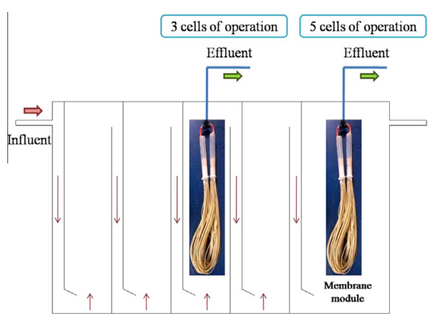
HIGHLIGHTS

- The membrane filtration was combined with anaerobic baffled reactor.
- The ABMBR without turbulence intensifying strategy was developed.
- Membrane fouling developed slowly under static operating condition.
- The polysaccharide accounted for 79.12% of total area of filter cake.
- Submicron particles in supernatant were the source of fouling in ABMBR.

GRAPHICAL ABSTRACT



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ABSTRACT

A novel AnMBR combined with ABR as the anaerobic baffled membrane bioreactor (ABMBR) was developed for membrane fouling mitigation without any turbulence intensifying strategy to reduce the energy consumption further. The filtration time of this system lasted 14–25 days under stable condition only with back-flushing every 48 h. The polysaccharide accounted for 6.85 ± 3.1% amount of total filter cake and the protein accounted for 4.12 ± 2.1%, which took 79.12% and 11.12% of total area in laser scanning confocal microscope (CLSM) image. After filtration, 83.72 ± 10.97% of turbidity, 59.28 ± 16.46% of polysaccharide, 16.51% of tryptophan and 37.61% of humic-like substrates were rejected, respectively. The total membrane resistance at the end of each cycle was $(4.47 \pm 0.99) \times 10^{13}\ m^{-1}$. And the resistance from filter cake was $(4.15 \pm 1.00) \times 10^{13}\ m^{-1}$, which accounted for of 92.6 ± 3.4% of total membrane resistance.

1. Introduction

The research and development of anaerobic membrane bioreactor (AnMBR) have been carried out comprehensively in recent years, because of its advantage in energy conservation, anaerobic microorganism retention and higher quality of anaerobic effluent (Lin et al., 2013; Liao et al., 2006). Although the effluent from AnMBR still contains ammonia nitrogen, phosphate from influent and high concentration of soluble organic matters (Gouveia et al., 2015; Skouteris et al., 2012), its potential application in agricultural irrigation and hydroponic system still makes this kind of wastewater treatment system popular in research. The high concentration of foulants and low intensity of turbulence without air aeration in anaerobic system can cause more serious membrane fouling phenomenon during filtration. Similar to membrane bioreactor (MBR), the configurations of AnMBR includes external cross-flow, internal submerged, or external submerged (Smith et al., 2012). For cross-flow system, the membrane fouling can be mitigated by the high speed of sludge flow (Skouteris et al., 2012), and additional turbulence is always applied in submerged AnMBR for fouling elimination (Ozgun et al., 2013). As there is artificially intensified turbulence, additional energy is necessary, which will weaken the advantage of AnMBR in energy

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consumption. And so far, many of the relative reports mainly focus on the novel membrane fouling mitigation technology in AnMBR for efficiency enhancement and energy consumption reduction during the operation (Skouteris et al., 2012; Ozgun et al., 2013).

For cross-flow AnMBR, the acceleration of sludge flow can intensify the fouling mitigation, but there is a balance between the speed and efficiency (Skouteris et al., 2012). For submerged AnMBR, biogas aeration is the most popular approach for fouling elimination (Ozgun et al., 2013), but the special equipments and extra energy consumption for biogas aeration are essential, besides the security must be concerned if it is applied in practice. In AnMBR, filter cake on membrane surface is considered as the main factor for permeate flux decrease (Skouteris et al., 2012), so the turbulence enhancement for filter cake removal is the most direct and effective approach. Some novel ways for membrane fouling mitigation have been proposed, which include ultrasound (Xu et al., 2013), transverse vibration (Kola et al., 2014), rotary disk stirring (Kim et al., 2014) and fluidized media (Aslam et al., 2014) or granule activated carbon (Gao et al., 2014) addition, etc. Those kinds of turbulence enhancement approaches still work based on energy consumption. And the addition of fluidized media or granule activated carbon also needs the assistance of biogas aeration. So, there are few AnMBR without additional energy consumption for fouling mitigation had been reported previously.

As the filter cake takes most of the fouling quotient, the turbulence is necessary for cake removal during operation. If no turbulence is applied, the cake formation could be reduced directly by reduction of the circumstance concentration of foulants (Metcalfe et al., 2016), which can also attain the goal of membrane fouling mitigation. In this case, the structure of the reactor should be improved. The anaerobic baffled reactor (ABR) is one of effective anaerobic wastewater treatment system (Hu et al., 2009). The ABR is composed by series of up-flow anaerobic sludge blanket (UASB), and the influent traverses the whole system in the form of reciprocation. The pollutants can be removed by the microorganisms when the wastewater flows through the sedimental sludge blanket (Lay et al., 2016). The footprint of wastewater is lengthened and the hydraulic retention time (HRT) can be separated from sludge retention time (SRT), so that the wastewater treatment efficiency is high and the operation is steerable (Hahn and Figueroa, 2015). The most important is that there is no turbulence during the treatment process, and there is no suspended sludge in supernatant at the top of each cell. If the ABR is combined with AnMBR, the membrane module assembled in the supernatant, which can be more efficient in mitigation of membrane fouling comparing with traditional submerged AnMBR, as the foulants concentration in supernatant is much lower than that in bulk sludge. And the total suspended solids in supernatant is reduced constantly when the treatment cell is added in ABR (Hahn and Figueroa, 2015), which means the concentration of membrane foulants in ABR would be reduced at the later cell. So the membrane fouling should be controlled effectively if the cell number of ABR and operation condition is appropriate.

In this study, a novel AnMBR combined with ABR as the anaerobic baffled membrane bioreactor (ABMBR) was proposed. The raw domestic wastewater was used as influent. The membrane module was set in the supernatant of ABR's later cell. The long-term operation was carried out to identify the membrane fouling behavior. The composition of membrane resistance was analyzed during the physical and chemical cleaning process, the structure of filter cake and fouled membrane were characterized, and the features of supernatant were revealed to identify the membrane fouling behavior in ABMBR. The parameters of water quality of supernatant in each cell were analyzed to identify the relationship between the pollutants transformation and membrane fouling behavior in this novel ABMBR.

2. Materials and methods

A 49 L polymethyl methacrylate ABR equipped with 5 cells was used in this study. The active volume of one cell was 8 L (for first four cells) and it was 11.5 L for the last cell for membrane module installation, respectively. The membrane used in this experiment was the self-produced hollow fiber polyvinylidene fluoride (PVDF) membrane with polyethylene terephthalate (PET) internal support, which with outside diameter of 2.5 mm and 31 pieces of membrane fiber were sealed in polyethylene tube in the form of "U" for one membrane module. Two membrane modules with total active area of 0.28 m^2 were used in parallel for dead-end filtration. In order to identify filtration and wastewater treatment efficiency of our ABMBR under different operational conditions, the membrane modules were installed in the 5th cell for the first two cycles, and then moved into the 3rd cell during the rest tests. The cover plate was sealed on the top of reactor with silicone gasket and bolts for anaerobic condition. The tube sealed on the cover plate was used for effluent and biogas spilling, and water sealing system was used for biogas collection. The whole system was operated for 130 days.

The raw wastewater for influent was drawn from the sewer at the campus of Xi'an University of Architecture and Technology after 3 pm each time, the water quality parameters of influent, supernatant and effluent during each operating condition were shown in Figs. S1–S3, which included chemical oxygen demand (COD), suspended solids (SS), ammonia nitrogen (NH_3-N), nitrite and nitrate nitrogen (NO_2^--N, NO_3^--N), phosphate (PO_4^{3-}) and were measured every one week according to the standard methods (APHA, 2005). And the wastewater was filtrated via sifter with 0.9 mm of pore size for big size of particles or suspended solids removal before using. The anaerobic sludge was taken from the bottom of UASB system of Hans brewery (Xi'an, China), which was filled in the ABMBR and the acclimatization process lasted for 30 days with continuous influent of domestic wastewater and without membrane filtration. For five cells of operation, a 5 L of anaerobic activated sludge with mixed liquor suspended solids (MLSS) of 48.05 ± 0.49 g/L was injected in the first four cells (sludge thickness of 35–38 cm), respectively. The initial MLSS was 30.03 ± 0.31 g/L (including the volume of supernatant) and with final MLSS of 32.71 ± 6.63 g/L in the 1st cell and 2nd cell together at the end of operation (including the volume of supernatant). For three cells of operation, most of the sludge was discharged from the 3rd cell (residual sludge thickness of 5–8 cm). For sludge containing cell, the level of sediment sludge was lower than the sampling hole, which was 45 cm from the bottom of reactor. For the cell with membrane module, the sludge level kept lower to make sure that the module stayed away from the sediments. And no regular sludge discharging was carried out during the whole operation.

The peristaltic pumps (Langer, China) were used for influent and effluent. The speed of influent was set at 1.11 L/h (7 rpm) with constant working. The speed for effluent was set at 4 L/m^2/h (8 rpm) with working mode of 5 min "on" and 1 min "off", which was controlled by the time switcher. The HRT for five cells of operation was 39.19 h and it was 21.62 h for three cells of operation. The transmembrane pressure (TMP) was shown via vacuum meter and the membrane resistance was calculated by Darcy's law (Liu et al., 2012).

The whole study included 9 operating cycles. The back-flushing was carried out by reversed influent pump every 48 h with 1 L of tap water from the 1st cycle to the 6th cycle, which lasted about 1 h and then followed the mode of 5 min "on" and 1 min "off". For the 7th, 8th and 9th cycles, the back-flushing was carried out every 24 h with 500 mL tap water for 30 min, because the