Bioresource Technology 194 (2015) 383–388

Contents lists available at ScienceDirect

Bioresource Technology

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

Review

Membrane bioreactor: A mini review on recent R&D works

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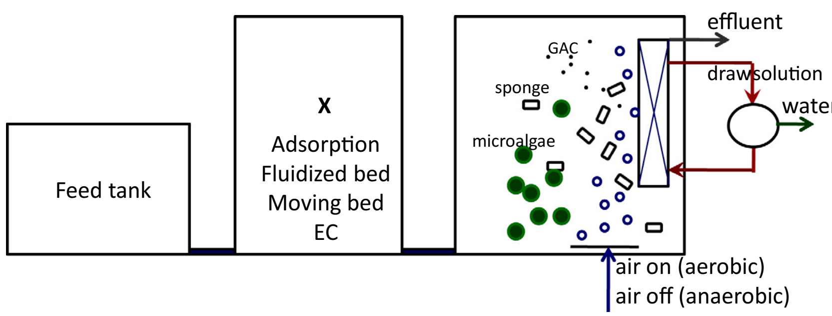
HIGHLIGHTS

- Novel MBR systems were developed and reviewed in this article.
- Revised MBR architectures and the use of hybrid systems are listed and discussed.
- Recent development of forward osmosis MBR is documented.
- Challenges and prospects of MBR technologies are highlighted.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 11 June 2015
Received in revised form 1 July 2015
Accepted 5 July 2015
Available online 20 July 2015

Keywords:
Hybrid MBR
Fouling mitigation
Osmotic membrane bioreactor
Solute leakage

ABSTRACT

Membrane bioreactor (MBR) has been widely applied worldwide in full scale. Recent research and development trends of MBR technology has been shifted from process optimization and economic evaluation to installation of new process architecture to enrich functional strains like nitrifiers or providing assisted field for performance enhancement, to incorporation of affordable adsorbents or scouring agent for membrane fouling mitigation, and to applying MBR hybrid systems for achieving simultaneous removals of nutrients and other pollutants. This mini-review summarized the recent works, principally in 2014–2015, on the above aspects, and provided a discussion on the osmotic MBR based on forward osmosis on its use of high-osmotic-pressure draw solution and the pre-treatment needed, and the reverse solute leakage that affects the MBR efficiency.

1. Introduction

Each year numerous studies were reported on all aspects of membrane bioreactors (MBR). The Web of Science™ database search using topic of MBR on 2015.06.06 led to a total of 3424 papers, in fields such as biotechnology applied microbiology (1135), energy fuels (963), electrochemistry (762) and environmental sciences (575), and with authors from United States and China contributing about 60% of these published papers. In all platforms, Bioresource Technology ranked top in number of MBR papers published (12%). Relevant review articles are available on recent progress and developments of MBR technologies, including those for nutrient/pollutant removal and recovery (Kelly and He, 2014), improvement of micro-scale MBR architecture for performance improvement (ElMekawy et al., 2014), use of MBR for abatement of hydrogen sulfide (Pikkar et al., 2015), as a desalination device (Subramani and Jacangelo, 2015) and as a bio-factory (Mohan et al., 2014). Besides, the anaerobic submerged MBR were studied for enhanced methane production (Robles et al., 2014; Gao et al., 2014a,b; Xie et al., 2014; Ding et al., 2014b). The MBR was applied to treat trace organic contaminants (TrOCs) representing

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http://dx.doi.org/10.1016/j.biortech.2015.07.013
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pharmaceuticals, steroid hormones, phytoestrogens, UV-filters and pesticides in the aqueous and solid phases (Wijekoon et al., 2013) or to recover phosphorus from wastewaters (Zuthi et al., 2013).

To reach various goals on wastewater treatments, novel MBR systems were developed. This mini-review lists a few recent studies on MBRs, from which the current R&D trends on MBR systems can be demonstrated.

2. Revised process architecture

The original architecture of an MBR consists of an aerated sludge reactor with an external membrane filtration unit (external MBR) or with a submerged membrane with suction (submerged MBR). Revised MBR architecture was proposed to enhance the removal performances in wastewater treatment. Sun et al. (2014) proposed an adsorption-MBR which put down an adsorption tank between an activated sludge tank and an MBR to receiving raw wastewater so the nitrifiers can be enriched. These authors noted enrichment of nitrifiers and improvement of sludge filterability by adoption of the adsorption-MBR system.

Shin et al. (2014) demonstrated the supreme process performance of a pilot-scale staged anaerobic fluidized membrane bioreactor when treating primary-settled domestic wastewater. Over wide temperature variation, the proposed system produced >90% biochemical oxygen demand (BOD) and chemical oxygen demand (COD) removal at low energy consumption. Gao et al. (2014a) studied the microbial community shifts in the operation of an anoxic–oxic-MBR. Incorporation of anoxic and oxic zones altered microbial community structure and enhanced nitrogen removal capability of an MBR.

Zhang et al. (2014) realized the completely autotrophic nitrogen removal over nitrite (CANON) process in MBR. The increased ammonia concentration and reducing hydraulic retention time strategy for rapid startup of the reactor was discussed.

Li et al. (2014) proposed a fluidized bed membrane bioelectrochemical reactor with added granular activated carbon for electricity generation and contaminant removal. These authors proposed that the studied system can reach energy neutral, at least theoretically.

Xu et al. (2014) tested an algae-based MBR with *Chlorella emersonii* as the seed. After 150 day operation, the algae concentration was increased from 385 to 4840 mg/L and removed 66% of the total P. Bilad et al. (2014a,b) proposed a membrane photobioreactor for cultivation and pre-harvesting the Chlorella vulgaris. The membrane completely retained the biomass, which then was partly recycled into the bioreactor to maintain a high biomass concentration, to operate at both high dilution and high growth rates. Ylitervo et al. (2014) applied submerged MBR to enrich density of Saccharomyces cerevisiae for fermenting toxic lignocellulosic hydrolyzate to ethanol. The MBR demonstrated rapid and productive ethanol production from wood hydrolyzate.

3. External additives

To mitigate membrane fouling, studies added external additives in the MBR to accelerate membrane scouring or to adsorb soluble foulants in suspension. Deng et al. (2014) noted that the added sponge can prevent cake formation and pore blockage in a submerged MBR that are mainly contributed by soluble microbial products in activated sludge. Zuthi et al. (2015) developed a mathematical model for a sponge submerged membrane bioreactor considering the biomass viability and extra-cellular polymeric substances redundancy. The model was validated by experimental data and was used for making process performance prediction.

Rezaei and Mehrnia (2014) added clinoptilolite (a nature zeolite) to increase the concentration of mixed liquor suspended solids, reducing the quantity of soluble microbial products in suspension and to reduce the transmembrane pressure drop. The presence of zeolite was proposed to enhance wastewater treatment performance and to ease the reactor operations.

Nguyen et al. (2013a) evaluated the performance of a pilot scale reactor consisting of a granular activated carbon (GAC)-sponge fluidized bed bioreactor and a submerge MBR. These authors noted that the tested pilot system could remove 90% dissolved organic carbon (DOC), 95% NH_4^+-N, and about 70% of PO_4^--P. The transmembrane pressure for the studied system remained low over the experimental period. Nguyen et al. (2013b) removed 22 trace organic contaminants by GAC and powdered activated carbon (PAC)+MBR. The application of MBR + GAC (two stages) and the MBR-GAC (one stage) processes enhanced removal of seven hydrophilic and biologically persistent compounds. Hu et al. (2014) investigated the performance of a pilot-scale MBR system with PAC addition for enhancing micropollutant removal from surface waters. Ding et al. (2014a) mitigate membrane fouling by adding GAC to a membrane-coupled expanded granular sludge bed reactor. Since the activated carbon can adsorb various extracellular substances, its presence alleviated membrane fouling efficiently.

Zhou et al. (2014) studied the effects of titanium dioxide nanoparticles on the cake layer formation in a submerged MBR. The nanoparticles had accelerated membrane pore blocking but postponed cake layer fouling, which was attributable to their inhibition of interactions between the inorganic and the organic compounds so SiO_2 were prevented from depositing onto the membrane surface.

Lin et al. (2014) studied the osmotic pressure build-up by accumulated counter-ions in cake layer in an MBR, which contributed to the high cake resistance during filtration. Hence, the removal of cake layer and/or incorporate foreign particles inside the fouling layer should be able to reduce cake resistance with filtrate flows. The detailed study on this mechanism remains lacking.

4. Hybrid processes

Guadie et al. (2013) and Gao et al. (2014b) studied a fluidized bed reactor (FBR)-MBR system for simultaneous phosphorus and nitrogen removal from sewage. These authors revealed that the tested system could have enhanced nitrogen and chemical oxygen demand (COD) removal to above 98.7% as phosphorus was removed in the FBR stage. Guadie et al. (2014) investigated the effect of intermittent aeration cycle on nutrient removal and microbial community structure in FBR–MBR system. The FBR alone process removed >85% PO_4^--P, <40% NH_4^+-N and <35% COD. The combo system almost completely removed COD and NH_4^+-N with Proteobacteria, Firmicutes and Bacteroidetes being the dominant bacterial group in all samples.

Nguyen et al. (2014a) evaluated a pilot scale system consisting of rotating hanging media bioreactor (RHMBR), submerged membrane bioreactor (MBR) along with electrocoagulation (EC). The tested system had almost complete removal of nitrogen and phosphorus from waters. Nguyen et al. (2014b) applied a pilot-scale system with equalizing reactor, rotating hanging media bioreactor and submerged flat sheet membrane bioreactor with internal recycles. With four times of feed flow rate as recycle, the removals of biological oxygen demand (BOD), COD, NH_4^+-N, total nitrogen (TN), total phosphorus (TP) and total suspended solids (TSS) were 99.88%, 95.01%, 100%, 90.42%, 73.44%, and 99.93%, respectively. With chemically cleaned-in-place, the membrane could continuously maintain a constant permeate flux at low power consumption.