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Fouling Challenges in Membrane Bioreactor

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ABSTRACT

Membrane bioreactor (MBR), as a promising technology, has been popular in wastewater treatment due to the great quality of effluent and system compactness. However, membrane fouling is still a main concern and complicated phenomena which has to be addressed and further studied by researchers and membranologists. In current mini review paper, the brief fundamental of MBRs and main challenges in MBR applications are summarized together with future perspectives that may be a help to research and development scientists.

Keywords: MBR, membrane fouling, wastewater treatment, cleaning, water reuse

INTRODUCTION

Membrane bioreactor (MBR) is a hybrid system includes a biological process and solid-liquid membrane separation unit (i.e., micro/ultrafiltration) applied for an efficient biomass retention. MBR process can be effectively applied in both municipal and industrial wastewater sectors and its worldwide market and capacity has been following a robust growing trend. The global MBR market was assessed approximately 1.2 billion USD in 2016, and has been expected to rise up 3.8 billion USD by 2023 with an annual growth rate of about 15% [1]. Submerged or immersed (iMBR) and sidestream (sMBR) are the two principal MBR technology process configurations [2]. The submerged configuration is more energy efficient and cost-effective [3], due to two main reasons: 1) aeration causes a liquid flow near the membranes and no recycle pump is required, and 2) the lower value of transmembrane pressure (TMP) applied.

Flat sheet (planar), hollowfiber (vertical-oriented), and multitube/multichannel are the general MBR technology configurations. The first two former configurations are mostly applied for iMBRs, both for industrial and municipal purposes; whereas, the latter one’s focus is often on treating lesser effluent flows from industrial installations. Selecting the suitable configuration is greatly depends on a specific use. Membrane characteristics such as membrane pore size, porosity/roughness, and hydrophilicity have been greatly reviewed. Polyvinylidene difluoride (PVDF), polypropylene (PP), polyethylene (PE), and polyethylsulphone (PES) are the leading materials used in manufacturing commercial MBR membranes. Compared with conventional activated sludge process, MBR has a several advantages including high effluent quality, small footprint, complete separation of hydraulic retention time (HRT) and

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solid retention time (SRT), low sludge production, and great biomass retention [1, 4, 5]. However, membrane fouling has negative effects on membrane performance and its lifetime. The objective of current paper is to summarize MBR main challenge – membrane fouling – in real life and to address the strategies to control and mitigate this phenomena in brief.

MEMBRANE FOULING ISSUES

As mentioned before, despite the great advantages offered by a current MBR technology in wastewater treatment over conventional counterpart; membrane fouling and channel clogging are yet a critical challenges and remaining as serious bottlenecks. Therefore, the development of a cost-effective membrane with high flux and low fouling tendency is still required for industrious demand. Fouling phenomena increases the total membrane resistance, leading to a reduction in membrane flux and performance stemming from a formation of a deposit layer on the membrane surface, the diffusion of fine colloids and molecules in the pores. Clogging is the accumulation of coarse solids within or at the channel entries, they may respectively refer as sludging or ragging/braiding [2, 6, 7].

Frequent cleaning, further energy demand for aeration, and operation/maintenance costs are the other main drawbacks of a membrane fouling. Fouling phenomena is a complicated interactions amongst the membrane properties, the components of suspended solids, and operating parameters [1, 5]. Operational and hydrodynamic conditions, permeate flux, temperature, biomass concentration/characteristics and microbial community are other significant parameters impact fouling. Sludge properties can also directly affect cake layer formation. Membrane fouling is generally categorized based upon foulant components into organic, inorganic and biological types of fouling. The former two types, respectively, are due to macromolecular species and scales. Biofouling refers to the biofilm deposition, and extracellular polymeric substances (EPS) and soluble microbial product (SMP) adsorption on membrane and within pore surfaces. It should be pointed out that all the three fouling forms can occur concurrently in real life [2, 4, 6, 8].

MBR fouling mechanism typically follows a three-stage process: 1) conditioning fouling, 2) steady fouling, and 3) TMP jump. At first stage, strong interactions occur between membrane surface and colloids/organics and irreversible fouling forms due to the initial rapid adsorption. Further adsorption and attachment of organics on the membrane surface lead to the second stage. Permeability is declined when membrane surface is fouled. So, permeation is higher in some less fouled areas and surpassing a critical flux. As a result, the fouling rate rises approximately exponentially with flux (in constant flux operation).

MEMBRANE FOULING CONTROL STRATEGY

Many attempts have been carried out to improve membrane fouling control. The prevalent strategies and certain practices applied to mitigate the fouling frequency are known as pre-treatment, addition of coagulants/flocculants, improving operating parameters, membrane modification, hydraulic characteristics and efficient membrane cleaning. Concentration polarization related fouling can be mitigated by increasing turbulence and decreasing the flux. Turbulence can be augmented by increasing the membrane aeration/crossflow velocity (CFV) [2]. A moderate hydraulic condition and crossflow stream along the membrane can help reducing sludge deposition on membrane surface. Thus, aeration and CFV can impact TMP, and consequently impact membrane fouling [9].

Physical, chemical and both can be employed to clean membranes. Regular physical cleaning is typically accomplished either by backflushing (with/out air, in case of hollow fibers) and relaxation (in case of flat sheets); which is frequently utilized, in case of reversible fouling, to remove the loose outer deposit layer consolidation. Chemical cleaning is the maintenance cleaning, in case of irreversible fouling, using chemicals such as sodium hypochlorite, citric acid, nitric acid, and sodium hydroxide without removing the modules from the tank. It may be also known as cleaning in place (CIP). If a lower concentration of chemical cleaning agent is added to the backflushing, it is known as a chemically enhanced backflush (CEB). However, after all cleaning procedures, there is still irrecoverable fouling in the original membrane throughout an operation. Chemical cleaning is more severe and sometime more effective than physical cleaning. It should be noted that overdue or inadequate chemical cleaning leads to the shorter modules' lifetime and higher replacement cost. In case of clogged membrane with heavy agglomerated materials, immersed membrane modules should be removed from the train to manually inspect and clean sludge solids [2, 6].

Membrane material selection and surface modification (i.e., plasma treatment, surface coating, surface grafting, etc.) are interesting common areas to focus and develop novel membranes with lower fouling tendency. Using fine screens in pre-treatment (less or equal to 1 mm) can perform as a better barrier to prevent coarse solid materials and protect both the membrane unit and bubble diffusers. Uniform and adequate aeration of the membrane sheets or fibers shows a direct impact on the cleanliness of the membranes. Therefore, the aerator's design and optimization of operational conditions are important tasks [2, 6].

Microbial group behaviors produced by quorum sensing (QS) using signal molecules have critical impact on biofilm formation and MBR biofouling. To overcome this phenomena, inactivation of signal molecules has been employed as an anti-biofouling strategy, so-called quorum quenching (QQ) approaches [10].

FUTURE PERSPECTIVES

This paper discusses the solid advantages along with some limitations of practical MBR process. With that said, further studies should be involved in better understanding of these barriers and their improvement in future. Further full/industrial-scale research and data both in the labs and from the wastewater treatment fields are required to elaborate on the membrane and operational concerns. QS/ QQ is a relatively new horizon of MBR process and need further investigation and more attention.

CONCLUSIONS

MBR technology is an efficient and a potential alternative for treating industrial and municipal wastewaters over conventional methods. Membrane fouling and its consequences is still a major MBR drawback limiting its applications; further approaches should be researched and applied to control this phenomena. The development of anti-fouling membranes with high durability and lifecycle in real life is undoubtedly necessary for future.

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