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Full Length Research Paper

Current research and development of controlling membrane fouling of MBR

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Fouling is a major problem influencing the operational performance, stability and cost of a membrane bioreactor (MBR). The composition of wastewater and biomass grown in the MBR are directly related to fouling. Many factors including operational parameters can affect the fouling process. The extent of fouling can be controlled by employing proper operational strategy, improving membrane materials and proper designing membrane module and reactor configuration. This paper describes major factors related to membrane fouling as well as further research needs.

Key words: Membrane bioreactor, membrane fouling, trans-membrane pressure, flux.

INTRODUCTION

Water shortage is a world-wide problem including China and most African countries. The membrane bioreactor (MBR) is a treatment system that combines both activated sludge process and membrane separation process. Because of the high efficiencies of removal of organic pollutants and separation by this process, the effluent of MBR can be reused for irrigation, lawn watering, cleaning or cooling water on industrial sites, toilet flushing and other purposes. Biomass concentrations within MBRs can reach as high as up to 20 g/L, resulting in high volumetric organic removal rate and compact reactor space. This process also presents several other advantages such as ease of handling, compact and lower excess sludge (Gui et al., 2003; Komesli et al., 2007). At present, thousands of MBR plants are operated over the world. It is believed that MBR will become more and more popular in next decades. Like other membrane processes, however, membrane fouling is a major technical issue for MBR process. Fouling decreases permeate flux and membrane lifespan. Membrane cleaning has been regular operational procedure and replacement of membrane is required when membrane fouling/clogging become irreversible (Figure 1). All above lead to the increasing costs on operation and maintenance (Fletcher et al., 2007; Jeison and Lier, 2007; Viero et al., 2007). For decades, prevention of membrane fouling is still technical challenge.

During the past decades, many researches have been done on membrane fouling in relationship to material characteristics, operational parameters, sludge characteristics, and reactor design, etc. This paper describes major factors related to fouling as well as further research needs.

MAJOR FACTORS AFFECTING FOULING

MBR is composed of membrane separation modules and biological treatment unit. Therefore, the operating issues not only include conventional factors such as biological and reactor kinetic parameters but also the parameters of membrane separation. The biochemical kinetics parameters are: sludge retention time (SRT), hydraulic retention time (HRT), sludge concentration, volumetric loading rate, and specific sludge loading rate. Temperature also influences the reactor operation. The parameters of membrane separation include inherent characteristics of membrane (membrane material, pore size and surface charge), characteristics of mixed liquor (viscosity, inorganic content), operational style and reactor hydraulic conditions. The biological characteristics have greater im-

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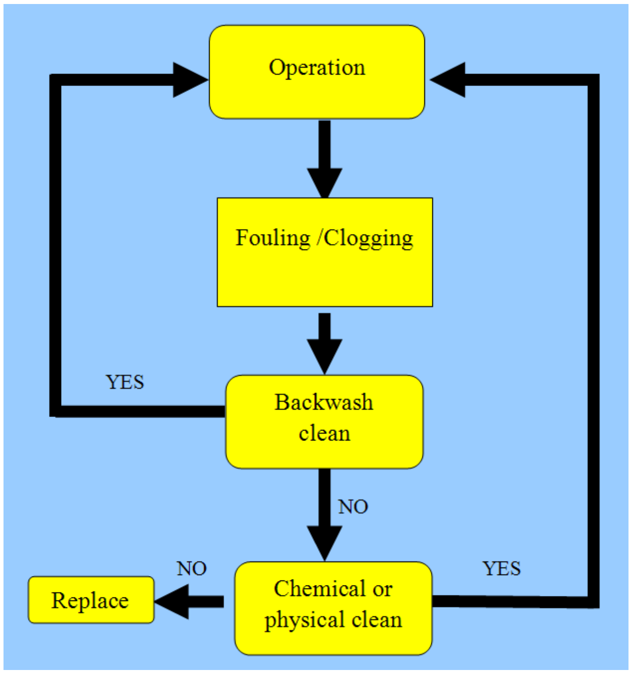

Figure 1. Membrane cleaning protocols. After a long time operation of MBR, fouling or/and clogging occur. Usually, backwash clean is used to mitigate fouling. Chemical or physical clean will be needed if backwash does not work. After several times of chemical or physical clean, the membrane should be replaced if its performance were not recovered.

pact on MBR efficiency, and the parameters of membrane separation mainly affect the treatment ability. As a result of the accumulation of particles from wastewater with a certain level suspended solids, a cake forms on the surface of membrane. When particles block the membrane pores, this is called pore plugging. Resistance as a consequence of adsorption in or on membrane is called fouling (Sombatsompop et al., 2006). Both biological and membrane separation parameters are related to forming fouling (Hilal et al., 2004; Asatekin et al., 2006; Kima et al., 2007) as illustrated in Figure 2. Membrane material, design of modules and operational process quite differently effect on the wastewater treatment efficiency (Guglielmi et al., 2007).

MEMBRANE MATERIALS AND MODULE STRUCTURE

Membrane materials

Membrane materials can be divided into two types: organic and inorganic. Organic polymer membrane material includes: polyolefin, polyethylene, PAN, PSF, aromatic polyamide, fluoropolymers, etc. Inorganic membrane is semi-permeable film made by inorganic material such as metals, metal oxides, ceramics and porous glass zeolite. Currently, most full scale MBRs use organic polymer membrane because of low cost, convenience of control and small aperture size. The hydrophilicity and surface charge of membrane material, to a certain extent, influences the progress of fouling and membrane clean-up (Chen et al., 2007). Compared to hydrophobic membrane material, hydrophilic membrane material is apt to absorb certain proteins and carbohydrates, and the obstruction rate of the hydrophilic membrane hole is vulnerable to increase. You and Kwon (2000) found that under the same con-ditions, hydrophobic membrane had higher flux than the hydrophilic one, and hydrophobic membrane, if its charge was the same to wastewater solution, could slow down membrane fouling to a certain extent as a result of the resistance of the same charge. According to our lab tests, the more hydrophobic the membrane is the higher flux and stronger anti-fouling performance.

Module structure

In order to facilitate the installation and industrialization, improve the efficiency of separation, and achieve the high specific membrane area per volume, membrane is usually assembled in a basic unit in form of a certain shape. This basic unit that completes the separation process is called membrane module.

The membrane module can be set inside or outside of the bioreactor, thus MBR can be divided into two basic types: submerged MBR and sidestream MBR (Figure 3). Membrane commonly used in water and wastewater processes includes at least five types, that is, frame, spiral-volume, tube type, hollow-fiber, and capillary type. The former two types can be classified as flat membrane and latter three types as tube membrane. The tube type and hollow-fiber type are widely used at full-scale MBR.

Different forms of module have their own advantages and disadvantages, so it is of great importance to select the appropriate membrane module and the proper combination form in order to ensure the treatment efficiency.

Operating process of MBR

Generally, fouling, that is caused by the accumulation of suspended or precipitated solids on membrane surface or in the membrane pores, results in a decrease of MBR performance. Operating process has great impact on membrane fouling. For example, during biological treatment, bio-substances like extracellular polymeric substances (EPS) can form colloid group, which is absorbed and deposited on the surface of membrane, blocking membrane pores and decreasing permeate flux. Micro-organisms also grow on the membrane surface.

Temperature

Temperature mainly influences the rate of bioreaction in

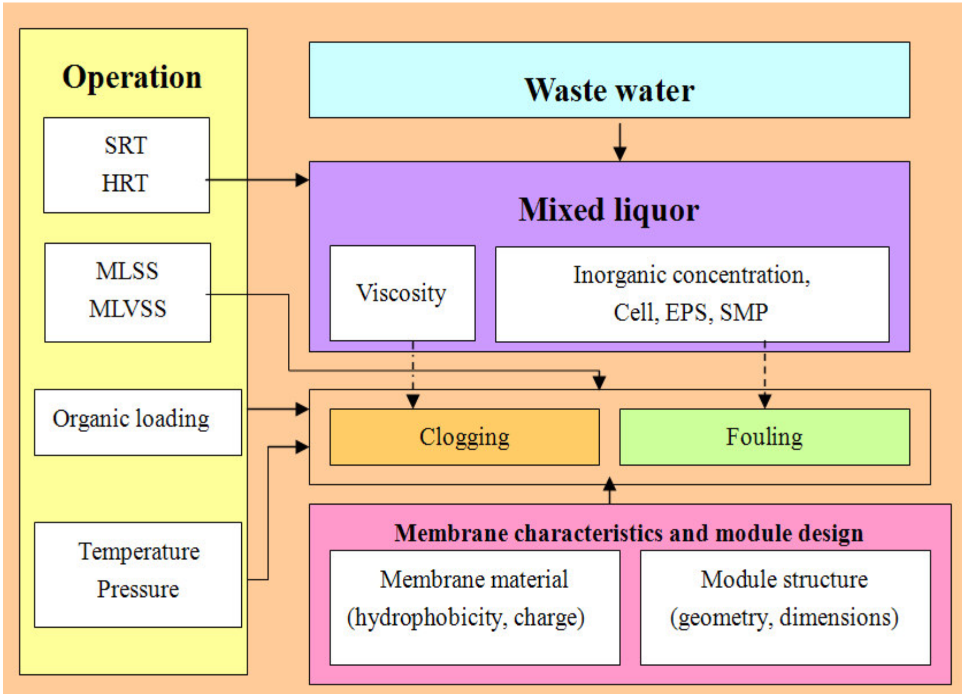

Figure 2. Inter-relationships between MBR parameters and fouling.

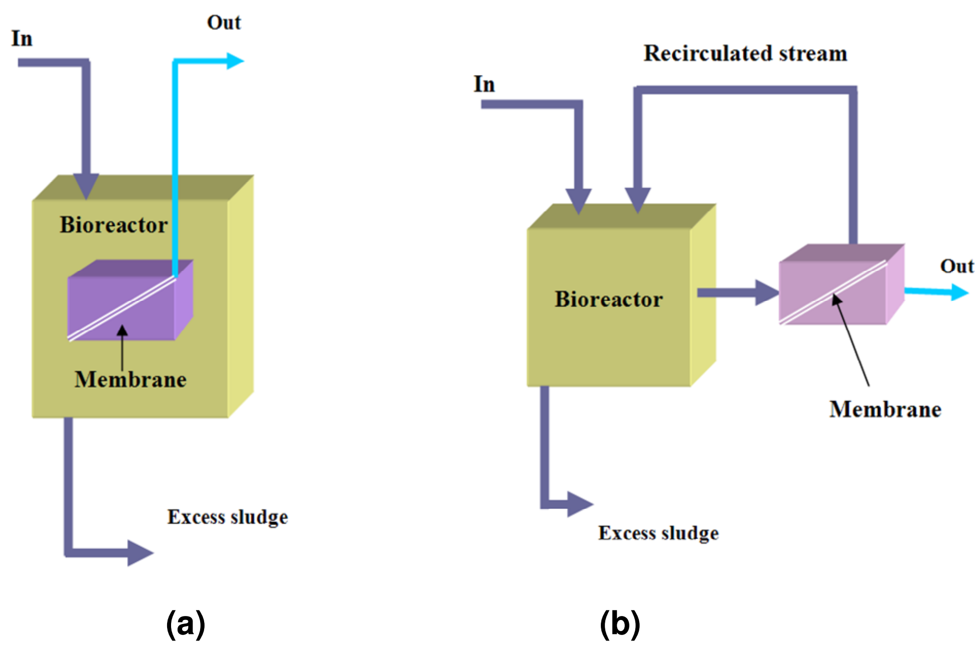

Figure 3. Submerged MBR (a) and sidestream MBR (b).

MBR. Generally, for both inorganic and organic membrane, the influence of temperature on membrane fouling is relatively slight. Peng and Liu (2000) reported that under constant pressure conditions, the system flux increased as the temperature increased. If both the Transs-membrane pressure (TMP) and biomass concentration are constant, the rise of system temperature, within a certain range, will cause a linear trend of increasing of permeate flux, which mainly attributes to the lower viscosity of the mixed liquor at higher temperature.

Organic loading rate

As organic loading rate increases, the concentration of soluble organics near the membrane increases and the polarization effect increases. This results in gradual formation of a layer of cake, acceleration of the resistance, and increase of pressure over the membrane. The membrane pressure could increase rapidly in a short time as organic loading rate increases, which indicate the beginning of membrane fouling. Therefore, organic load-ing rate should be controlled within a proper range to avoid the system burden (Trussell et al., 2005).

Sludge retention time (SRT)

Sludge retention time (SRT) is a function of organic loading rate and mixed liquor suspended solids (MLSS). For MBRs, the membrane separation process allows a high MLSS and long SRT. MBR can be operated at long SRT (10 - 100 days) or low sludge yield. This improves the ability of oxidation of ammonia to nitrite/nitrate and degradation of organic substances. SRT directly influences TMP. In general, the longer SRT, the lower concentration of ESP (Laera et al., 2007). On the other hand, the longer SRT, the higher deactivation of microorganisms which results in accumulation of inorganic substances. The ratio of MLVSS vs. MLSS could decrease. Some researches suggested that discharge of sludge regularly is needed to alleviate membrane fouling (Feng et al., 2003).

Hydraulic retention time (HRT)

After a membrane module and reactor size are selected, the HRT becomes a decisive parameter influencing permeate flux. A long HRT requires low permeate flux, while a short HRT increases the flux and the concentration of dissolved organic matter (such as SMP) in reactor, resulting in acceleration of membrane fouling and eventually, declining permeate flux (Jeong et al., 2007).

Operating pressure

The flux increases, within a certain range, as the operating pressure increases. However, it will no longer increase when the operating pressure is beyond the critical pressure. The increase of flux can increase the efficiency and treatment capacity of reactor, but speeds up membrane fouling (Taewoo et al., 2007).

In a MBR, the tangential flow along the membrane creates significant shear stresses. As the shear velocity rises, TMP increases and, fouling is peeled off by the tangential flow under a high shear velocity. In this way, fouling substance may not apt to deposit on the surface of membrane.

MLSS and MLVSS

In general, the high concentration of sludge (MLSS) causes the low capacity of permeation. The sludge will deposit on the surface of membrane easier if the MLSS increases (Sven et al., 2007). Under a constant HRT, the biomass synthesis rate and endogenous respiration rate reaches a dynamic equivalence, and MLVSS eventually becomes stable. The accumulation of inorganic substances, digestion of dead biomass and other residual material lead to the increase of MLSS (or the decline of the fraction of active biomass in the sludge), which ultimately affects the MBR efficiency.

MECHANISM OF MEMBRANE FOULING

Microbial EPS and SMP

Microbial biofim or layer attached on membrane surface reduces the flux but it can be controlled or removed by backwash. In general, there are two substances generated during biological activities causing fouling, that is, extracellular polymeric substances (EPS) and soluble microbial products (SMP). EPS is an insoluble macromolecule polymerized by microorganisms or substances like epidermis, capsule, gel and humic acid. SMP is produced by cell metabolism or self-digestion, which can be considered to be soluble, large molecules (Tarnacki et al., 2005). They form colloidal substances and gradually accumulate in the membrane hole, decreasing the effective pore size of the membrane.

Organic pollutants from wastewater

Organic pollutants, including organic macromolecules and polymers from wastewater, greatly reduce permeate flux after forming a colloid layer on membrane surface. In addition, Rosenberger et al. (2006) indicated that dissolved organic carbons caused increase of sludge viscosity. The increased viscosity and thus increase in filtration resistance result in the attachment of EPS on membrane surface, which grows up a gel layer on membrane. Studies also indicated that the decline of MBR flux can be attributed to the active sludge, composition of mixed liquor, EPS and dissolved organic matter such as colloidal particle.

Inorganic pollutants

In general, inorganic pollutants only influence on the fouling of anaerobic MBR. Choo et al. (1996), in their study of an anaerobic MBR, found that the micro colloid in broth is the main reason causing membrane fouling. They also found that it is the interaction of metallic/nonmetallic ions and cellular substances that forms dense cake layer on the surface of membrane. Calcium and magnesium are the major inorganic pollutants. Many studies showed that in the process of membrane filtration, calcium plays an important role in fouling. On one hand, low solubility of calcium salts cause concentration polarization on the surface of membrane, as well as precipitation, such as $CaCO_3$, $CaSO_4$. On the other hand, calcium leads to the change of biomass characteristics and accelerating of fouling.

CURRENT RESEARCH TOPICS

To date, research on fouling mechanism still continues in order to properly design reactor system, improve operational performance, and develop new membrane with anti-fouling properties. The research on fouling mechanisms, improvement of membrane materials and MBR process design will be an effective way to solve fouling problem and provide better cost-effective treatment (Lee et al., 2007; Hwang et al., 2007). The following research topics can be considered:

(1) The mechanism on fouling has been studied for years. More research works are still needed especially on fouling mechanism related to microbiology. As we understand, improvement in operating process or pretreatment of wastewater can slow down fouling progress to a certain extent but the membrane fouling can not be avoided completely due to microbial activity. Microbial activity, secretion, degradation process, product of metabolism and apoptosis will affect the permeability of membrane (Germain et al., 2007). Therefore, further researches from many aspects on the mechanism of fouling, especially on microbiology including the microbial community, microbial species responsible to fouling as well as their ecophysiological role etc, is the key to understand and control membrane fouling.

(2) More researches should be focused on characteristics of membrane materials (like surface charge, hydrophobicity) in order to develop anti-fouling materials. High-energy consumption of MBR is one of the limiting factors of MBR development. Increasing operating pressure or aeration strength is the most common method to enhance permeate flux. But this also results in higher energy consumption and higher operational cost. By changing surface charge, we may reduce energy consumption and decelerate fouling progress effectively. Development of high-performance and low-cost organic membrane materials will help MBR to become more cost-effective in the future.

(3) The effect of biological toxicity of pollutants in MBR has received fewer studies. A large number of toxic substances seriously affect the microbial community and has been studied in other biotreatment systems such as activated sludge process. Their impact on MBR should be studied. This will not only expand the application of MBR, which means treating different kinds of wastewater, but also enhance the biological activity and treatment efficiency.

(4) At present, most operating issues of MBR are derived from the pilot studies or previous operational experiences. A little research has been done in modeling MBR. Development of mathematical models for different MBR system will help to optimize the operational performance, process control and dealing with fouling.

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REFERENCES

Asatekin A, Adrienne M, Seoktae K, E Menachem, M Eberhard, M Anne M (2006). Antifouling nano-filtration membranes for membrane bioreactors from self-assembling graft copolymers. J. Membr. Sci. 285: 81-89.

Hwang BK, Lee WN, Park PK, Lee CH,Chang IS (2007). Effect of membrane fouling reducer on cake structure and membrane permeability in membrane bioreactor. J. Membr. Sci.288:149-156.

Choo KH, Lee CH (1996). Effect on anaerobic digestion broth composition on membrane permeability. Wat. Sci. Technol. 34: 173-179.

Fletcher H, Mackley T, Judd S (2007). The cost of a package plant membrane bioreactor. Wat. Res. 41: 2627-2635

Germain E, Nelles F, Drews A, Pearce P, Kraume M, Reid E, Judd S, Stephenson T (2007). Biomass effects on oxygen transfer in membrane bioreactors.Wat. Res. 41: 1038-1044.

Hilal N, Al-Zoubi H, Darwish NA, Mohamma AW, Arabi MA (2004). A comprehensive review of nanofiltration membranes:treatment, pretreatment, modelling and atomic force microscopy. Desalination, 170: 281-308.

Jeison D, Lier JB (2007). Thermophilic treatment of acidified and partially acidified wastewater using an anaerobic submerged MBR: Factors affecting long-term operational flux. Wat. Res. 41: 3868-3879.

Jeong TY, Cha GC, Yoo IK, Kim DJ (2007).Characteristics of bio-fouling in a submerged MBR. Desalination, 207: 107-113.

Chen JP, Yang CZ, Zhou JH, Wang XY (2007).Study of the influence of the electric field on membrane flux of a new type of membrane bioreactor. Chem. Eng. J. 128: 177-180.

Komesli OT, Teschner K, Hegemann W, Gokcay CF (2007).Vacuum membrane applications in domestic wastewater reuse. Desalination, 215: 22-28.

Laera G, Giordano C, Pollice A, Saturno D, Mininni G (2007). Membrane bioreactor sludge rheology at different solid retention times. Wat. Res. 41: 4197-4203.

Lee WN, Chang IS, Hwang BK Park PK, Lee CH, Huang X (2007). Changes in biofilm architecture with addition of membrane fouling reducer in a membrane bioreactor. Process Biochem. 42: 655-661.

Feng L, Zhang LQ, Lv BN (2003). Effect of sludge concentration on operational characteristics of membrane bioreactor. J. Harbin Inst. Tech. 35(3): 307-310.

Gui P, Huang X, Liu R, Sun YF, Qian Y (2003).Hydrodynamic effect on sludge accumulation over membrane surfaces in a submerged membrane bioreactor. Process Biochem. 39(2): 157-163.

Rosenberger S, Laabs C, Lesjean B, Gnirss R, Amy G, Jekel M, Schrotter JC (2006). Impact of colloidal and soluble organic material on membrane performance in membrane bioreactors for municipal wastewater treatment. Wat. Res. 40: 710-720.

Kima SD, Cho J, Kim IS, Vanderford BJ, Snyder SA (2007). Occurrence and removal of pharmaceuticals and endocrine disruptors in South Korean surface, drinking, and waste waters. Wat. Res. 41: 1543-1553.

Sombatsompop K, Visvanathan C, Benaim R (2006). Evaluation of biofouling phenomenon in suspended and attached growth membrane bioreactor systems. Desalination, 201: 138-149.

Sven L, Djamila AH, Thomas W et al (provide the compete names) (2007). Polymeric compounds in activated sludge supernatant--Characterisation and retention mechanisms at a full-scale municipal membrane bioreactor. Wat. Res. 41: 3894-3902.

Taewoo Yi, Willie F, Harper Jr (2007). The effect of biomass characteristics on the partitioning and sorption hysteresis of 17a-ethinylestradiol. Wat. Res. 41: 1543-1553.

Tarnacki K, Lyko S, Wintgens T, Natau F (2005). Impact of extra-cellular polymeric substances on the filterability of activated sludge in membrane bioreactors for landfill leachate treatment. Desalination, 179: 181-190.

Trussell RT, Merlo RP, Hermanowicz SW, Jenkins D (2006). The effect of organic loading on process performance and membrane fouling in a submerged membrane bioreactor treating municipal wastewater. Wat. Res. 40: 2675-2684.

Viero AF, Geraldo LS, Nobrega R (2007). The use of polyetherimide hollow fibres in a submerged membrane bioreactor operating with air backwashing. J. Membr. Sci. 302: 127-135.

You J, Kwon SK (2000). Production of chitooligosaccharides using an ultrafiltration membrance reactor and their antibacterial activity. Carbohydrate Polymers 41: 133-141.

Peng YL, Liu ZZ (2000). Several factors affecting membrane flux in membrane bioreactor. Technology of Water Treatment. 26: 326-332.