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A review on dynamic membrane filtration: Materials, applications and future perspectives

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ABSTRACT

This paper presents a comprehensive evaluation of the current status of dynamic membrane (DM) technology as an alternative to membrane bioreactor (MBR) systems. DM filtration makes use of a physical barrier (e.g. cloth or mesh) on which a cake layer is formed. It is already used in traditional filtration systems, but applications in biological wastewater treatment are still at its infancy. Dynamic filtration of sludge has lower risk of fouling and requires less energy and lower capital costs compared to MBR. A review of the state-of-art in both DM materials and configurations is presented. Factors affecting DM performance are discussed in order to determine the optimum and critical approaches for membrane operation. Future perspectives to enhance the applicability and functionality of the technology regarding the treatment and membrane performance are presented.

1. Introduction

Membranes have been used as solid–liquid separation devices in biological treatment (aerobic and anaerobic) and physical applications for many years. There has been a growing interest in combining membranes with biological wastewater treatment in so called membrane bioreactors (MBRs), giving striking advantages such as improved effluent quality and low system footprint (Judd, 2006). The major constraints of MBR processes are related to membrane costs, energy demand, fouling control, and low flux. Dynamic membrane (DM) technology may be a promising approach to resolve problems encountered in MBR processes (Fan and Huang, 2002; Wu et al., 2005; Ye et al., 2006). A DM, which is also called secondary membrane, is formed on an underlying support material, e.g. a membrane, mesh, or a filter cloth, when the filtered solution contains suspended solid particles such as microbial cells and flocs. Organics and colloidal particles which normally result in fouling of the membrane will be entrapped in the biomass filtration layer, preventing fouling of the support material (Kiso et al., 2005; Jeison and van Lier, 2007a,b). An illustration adapted from Lee et al. (2001) is given in Fig. 1 to demonstrate the dynamic cake layer formation. Formation of this cake layer over the membrane surface can determine rejection properties of the system since the deposited layer will act as a "secondary" membrane prior the "real" membrane or support material (Kiso et al., 2000; Park et al., 2004; Fuchs et al., 2005; Jeison et al., 2008; Zhang et al., 2010). Water backwash, air backwash, or brushing can be enough for DM cleaning without using chemical reagents (Chu et al., 2008). However, depending on the support material, cleaning obviously might be accompanied by a temporary loss of effluent quality.

One of the most important potential benefits of DM is that the membrane itself may be no longer necessary, since solids rejection is accomplished by the secondary membrane layer which can be formed and re-formed as a self-forming dynamic membrane (SFDM) in situ. Repeated processes of DM formation and removal may reduce membrane permeability losses as encountered in conventional MBRs (Lee et al., 2001).

Different kinds of cheap materials such as mesh, non-woven fabric and woven filter-cloth can be used as the supporting layer instead of microfiltration (MF) or ultrafiltration (UF) membranes for creating a DM layer (Wu et al., 2005; Chu and Li, 2006; Jeison et al., 2008; Zhang et al., 2010). Substituting the traditional membranes by cheaper filtration materials potentially offers higher flux rates at lower transmembrane pressures (TMPs) in a cost-effective manner (Seo et al., 2002; Fuchs et al., 2005; Satyawali and Balakrishnan, 2008).

Since 1960s, many DM studies have been conducted extending from physical filtration trials to MBR applications. Due to the variability of DM formation mechanisms and DM applications, a

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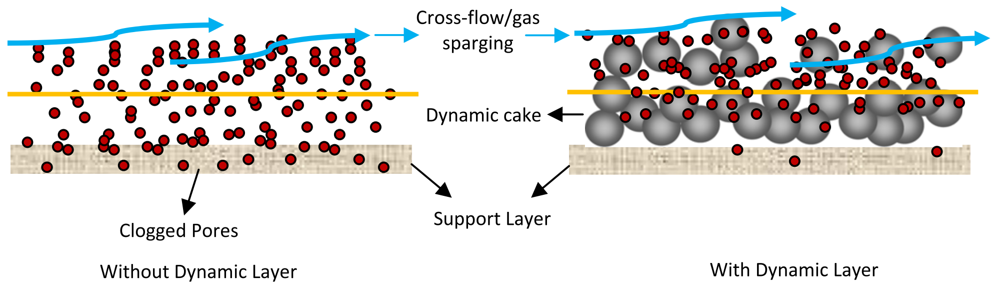

Fig. 1. Demonstration of the dynamic cake layer.

comprehensive study is needed to give direction to future studies on DM technology. This review summarizes DM studies and evaluates the results in many aspects, trying to better understand the DM formation mechanisms. Challenges encountered and future perspectives are discussed to enhance the functionality of DM technology.

2. Materials, configurations and historical development

2.1. Materials

2.1.1. Dynamic layer forming materials

DMs can be mainly classified into two groups, i.e. self-forming and pre-coated. SFDM is generated by the substances present in the filtered liquor, such as suspended solids (SS) in wastewaters, whereas pre-coated DMs, also denominated formed-in-place (FIP) membranes, are produced by passing a solution of one or more specific colloidal components over the surface of a porous material (Al-Malack and Anderson, 1996; Ye et al., 2006). The main disadvantage of this approach over SFDM is the requirement of an external material. The pre-coated DMs can also be subdivided into two groups, namely single additive and composite (bi-layer) membranes. The single additive pre-coated membranes are generally formed by only one material in a single step. Ye et al. (2006) used powdered activated carbon (PAC) as a single additive to form DM. Composite membranes are generally produced by a two-step formation process (Ip, 2005).

The concept of SFDM formation by microbial flocs has been applied to aerobic MBRs for wastewater treatment with promising results (Fuchs et al., 2005; Kiso et al., 2005; Wu et al., 2005; Chu and Li, 2006). Also the pre-coating method has been used to form a pre-coated dynamic layer in aerobic dynamic membrane bioreactors (DMBRs). PAC (Ye et al., 2006), kaolinite (Li et al., 2006) and bio-diatomite (Chu et al., 2008; Cao et al., 2010) are some of the ingredients that have been used as pre-coating materials. For anaerobic applications, SFDM method was applied by Jeison et al. (2008); whereas an example of surface modification with polytetrafluoroethylene (PTFE) can be found in study of Ho et al. (2007).

Hydrous metal oxide, especially zirconium (Zr(IV)) oxide, is one of the most commonly used and most successful material to form a DM layer in physical dynamic filtration (Marcinkowsky et al., 1966; Freilich and Tanny, 1978; Ohtani et al., 1991; Rumyantsev et al., 2000). Moreover, modification of Zr(IV) oxide with polymers, generally with poly(acrylic acid) (PAA), was also applied in order to improve the filtration properties of the dynamic layer (Altman et al., 1999). Other materials including MnO_2 (Al-Malack and Anderson, 1996; Cai et al., 2000), TiO_2 (Horng et al., 2009), $Mg(OH)_2$ (Zhao et al., 2006), gelatin (Tsapiuk, 1996), ovalbumin (Matsuyama et al., 1994), solid particles present in pineapple juice (Jiraratananon et al., 1997), kaolin (Wang et al., 1998; Noor et al., 2002), kaolin/MnO_2 bi-layer (Yang et al., 2011), poly(vinyl alcohol) (Na et al., 2000), dextran (Wang et al., 1999), non-coagulating and hydrophylized coagulating polymer (Knyazkova and Kavitskaya, 2000), and clay minerals (Kryvoruchko et al., 2004) have also been tested as forming materials of DMs.

2.1.2. Support materials

Research on DMs, especially for wastewater treatment has been generally focused on the use of meshes, woven and non-woven fabrics as the support material. A mesh consists of a permeable barrier made of connected strands of metal, fiber or other flexible/ductile material. The disadvantage of a mesh filter material may be related to the inefficient sludge accumulation due to its flat structure (Kiso et al., 2005). A woven cloth is based on monofilament and/or multifilament yarn. Monofilament yarns are single extruded synthetic filaments and have smooth surfaces. A multifilament fiber consists of several fine monofilament fibers spun together to form the individual yarns that are eventually woven together. A non-woven cloth is defined as a sheet or web of natural and/or man-made fibers or filaments, excluding paper, that have not been converted into yarns, and that are bonded to each other (Hutten, 2007). Although the non-woven fabric is very thin, attachment of sludge particles has been observed in the pores among the fiber matrix which made the removal of the attached sludge from the filter interstices difficult in the long term operation (Kiso et al., 2005).

To date, meshes (Kiso et al., 2000; Fan and Huang, 2002; Kiso et al., 2005; Chu and Li, 2006; Satyawali and Balakrishnan, 2008; Jeison et al., 2008; Walker et al., 2009; Zhang et al., 2010), non-woven fabrics (Seo et al., 2002, 2007; Wu et al., 2005; An et al., 2009; Ren et al., 2010), woven fabrics (Pillay et al., 1994; Fuchs et al., 2005; Liu et al., 2009) and ceramic membranes (Li et al., 2006) have been reported as possible support materials for solid–liquid separation in both aerobic and anaerobic dynamic MBRs.

In physical applications, DMs have been successfully formed on a variety of organic and inorganic support materials, such as ceramic tube (Nakao et al., 1986; Ohtani et al., 1991; Tien and Chiang, 1999; Yang et al., 2011), stainless steel tube (Groves et al., 1983; Wang et al., 1999); polymeric membrane (Turkson et al., 1989; Cai et al., 2000); MF membrane (Igawa et al., 1977; Jiraratananon et al., 1997; Na et al., 2000; Hwang and Cheng, 2003), UF membrane (Tsapiuk, 1996; Na et al., 2000; Kryvoruchko et al., 2004), reverse osmosis (RO) membrane (Knyazkova and Kavitskaya, 2000; Kryvoruchko et al., 2004), and woven or non-woven fabrics (Al-Malack and Anderson, 1996; Altman et al., 1999; Rumyantsev et al., 2000; Horng et al., 2009). Stainless steel and ceramic tubes have been generally used in physical DM applications, especially in the early studies. High cost of these materials is the main disadvantage of using them. Thus, cheaper materials such as woven or non-woven fabrics have also been tested by various researchers.

2.2. Configurations

Generally, submerged flat sheet membrane modules have been used in DMBRs. This is probably due to the operational simplicity