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Utilization of Aerobic Granulation to Mitigate Membrane Fouling in MBRs

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Abstract. Membrane bioreactor (MBR) is a compact and efficient wastewater treatment and reclamation technology but it is limited by membrane fouling. The control of membrane fouling significantly increases operational and maintenance costs. Bacteria and their byproducts - extracellular polymeric substances (EPS) - are major contributors to membrane fouling in MBRs. A recent attempt at fouling mitigation is the development of aerobic granular sludge membrane bioreactor (AGMBR) through the integration of a novel biotechnology - aerobic granulation - and MBR. This paper provides an overview on the development of AGMBR to mitigate membrane fouling caused by bacteria and EPS. In AGMBR, EPS are used up in granule formation; and, the rigid structure of granules provides a surface for bacteria to attach to rather than the membrane surface. Preliminary research on AGMBR using synthetic wastewater show remarkable membrane fouling reduction compared to conventional MBR, thus enhanced membrane filtration. Enhanced performance in AGMBR using actual municipal wastewater in a pilot-scale has also been reported. However, further research is needed to determine AGMBR optimal operational conditions to enhance granule stability in long-term operations and in full-scale applications.

Keywords: aerobic granulation; AGMBR; membrane bioreactor (MBR); membrane fouling; wastewater treatment

1. Introduction

Current wastewater treatment technologies such as conventional activated sludge (CAS) struggle to meet regulatory discharge requirements in terms water quality. These systems fail to remove nutrients (nitrogen and phosphorus) to acceptable levels (Baeza *et al.* 2004; Oleszkiewicz and Barnard 2006). The presence of nutrients in water bodies results in excessive growth of aquatic plants (eutrophication) which leads to the deterioration of surface water quality (Smith *et al.* 1999). Eutrophication causes increased biomass of phytoplankton and macrophyte vegetation, growth of benthic and epiphytic algae, increased blooms of gelatinous zooplankton (marine environment), loss of commercial and sport fisheries, increased toxins from bloom-forming algal species, reduced carbon available to food webs, increased taste and odor problems, reduced species diversity, increased treatment costs prior to human use, and decreased aesthetic value of the water body (Smith and Schindler 2009; Badruzzaman *et al.* 2012). In addition, CAS produces large volumes of sludge that needs further stabilization for safe disposal. The handling of sludge significantly increases operational costs.

Membrane bioreactor (MBR) has emerged as a technology of choice for wastewater treatment over the conventional systems (Le-Clech *et al.* 2006; Meng *et al.* 2009; Drews 2010; Lin *et al.* 2012). An MBR is a hybrid of biological treatment and physical liquid-solids separation by membrane filtration

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(Chang *et al.* 2002; WEF 2011). MBRs have been successfully used for the treatment and reclamation of both municipal and industrial wastewaters (Brindle and Stephenson 1996; van Dijk and Roncken 1997; Ueda and Hata 1999; Chu *et al.* 2006; Mutamim *et al.* 2012; Friha *et al.* 2014). The technology offers the following advantages over CAS: high-quality effluent, higher volumetric loading rates, shorter hydraulic retention time (HRT), longer solids retention time (SRT), less sludge production, and potential for simultaneous nitrification/denitrification in long SRTs (Judd 2008; WEF 2011; Mutamim *et al.* 2013; Metcalf & Eddy Inc. *et al.* 2014). The inclusion of membranes in the system eliminates the need for secondary clarifiers. This elimination of secondary clarifiers and shorter HRTs results in significantly reduced footprint. In addition, the prolonged acclimatization of microorganisms due to the long SRTs in MBRs is suitable for the removal of recalcitrants.

However, the major drawback of MBR is membrane fouling (Kimura *et al.* 2005; Meng *et al.* 2009; Lin *et al.* 2014; Vanysacker *et al.* 2014). Membrane fouling is the deposition of particles on the membrane surface or inside its pores resulting in reduced membrane permeability. The decline in permeability reduces membrane performance and membrane lifespan (Chang *et al.* 2002). Common membrane fouling mitigation strategies in MBRs include air scouring, operational relaxation and backflushing, chemical backwashing or modification of membrane surface chemistry. These strategies significantly increase MBR operating and maintenance costs (Chang *et al.* 2002). Bacteria and their byproducts - extracellular polymeric substances (EPS) - have been identified as major contributors to membrane fouling in MBRs (Chang and Lee 1998; Meng *et al.* 2009; Lin *et al.* 2014). EPS are bacterial byproducts originating from microbial metabolites, cell lysis, or unmetabolized wastewater components (Drews 2010). EPS are known to significantly affect the physico-chemical properties of microbial aggregates such as surface charge, hydrophobicity, settling properties, flocculation, adsorption ability, etc (Sheng *et al.* 2010; Show *et al.* 2012). EPS primarily comprise proteins, polysaccharides (carbohydrates), humic acids, nucleic acids, lipids and uronic acids (Ng *et al.* 2010; Pan *et al.* 2010; Lin *et al.* 2014). It is generally accepted that proteins and polysaccharides are the major components of EPS (Liu and Fang 2003; Drews 2010; Sheng *et al.* 2010; Lin *et al.* 2014); and, they are the components typically measured as an indication of the amount of EPS. EPS are sub-divided into two, namely bound EPS and soluble EPS (also referred to as SMPs) (Lin *et al.* 2014). Bound EPS are further split into loosely bound EPS (LB-EPS) and tightly bound EPS (TB-EPS) (Liu *et al.* 2010). SMPs and bound EPS are considered the major foulants in MBRs (Chang and Lee 1998; Jang *et al.* 2006; Meng *et al.* 2009; Wang *et al.* 2014) as they have multiple interactions with all other foulants (Lin *et al.* 2014). The aggregation of biomass happens by the participation of bound EPS and SMPs, which provides a highly hydrated gel matrix (Chang *et al.* 2002; Jang *et al.* 2006). The hydrated gel matrix acts as a 'glue' to keep the microbial aggregates together. The 'glue' property of EPS is the main cause of membrane fouling.

By virtue of their significance in fouling, current research is focused on coupling a novel biotechnology, aerobic granulation, with MBR to mitigate membrane fouling due to bacteria and EPS (Li *et al.* 2005; Tay *et al.* 2007; Tu *et al.* 2010; Juang *et al.* 2011; Thanh *et al.* 2013). Research in this direction is gradually developing the aerobic granular sludge membrane bioreactor (AGMBR). AGMBR offers a unique advantage of utilizing EPS for granule formation; and once formed, the granules provide a surface for bacteria to attach to rather than the membrane surface. The large size and rigid structure of the granules is expected to play a key role in membrane fouling abatement. This paper provides an overview of the development of AGMBR and identifies areas for further research.

2. Membrane fouling in MBR

Membrane fouling can be classified into three: biofouling, organic fouling, and inorganic fouling (Spettmann *et al.* 2007). Biofouling refers to the attachment, growth and metabolism of bacteria or flocs on the membrane (Meng *et al.* 2009). Membrane biofouling is a two-step process, starting with early bacterial attachment, followed by multiplication of bacteria on the membrane surface to form a cluster of