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A critical review of extracellular polymeric substances (EPSs) in membrane bioreactors: Characteristics, roles in membrane fouling and control strategies

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ABSTRACT

Extracellular polymeric substances (EPSs) are key biological substances, which largely determine properties of sludge flocs, including hydrophobicity, adhesion, flocculation, settling and dewatering properties, and therefore significantly affect membrane fouling in membrane bioreactors (MBRs). Much progress has been achieved in understanding of EPSs and their interrelations with membrane fouling due to a large number of systematic papers published in the last three decades. In this paper, the fundamentals of EPSs including definitions, compositions and properties are summarized. The interrelations of EPSs with other foulants in MBRs are clarified. Roles of EPSs in membrane fouling mechanisms in MBRs are critically assessed. Furthermore, factors affecting EPSs production and characteristics are summarized, and based on which, EPSs control towards membrane fouling mitigation in MBRs are comprehensively discussed. Finally, future research perspectives regarding EPSs and membrane fouling are proposed.

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1. Introduction

Membrane bioreactor (MBR) technology features various distinct advantages over the conventional activated sludge process, including excellent effluent quality, good disinfection capability, higher volumetric loading, reduced footprint and sludge production, process flexibility towards influent changes, and improved nitrification. These advantages, together with the more stringent discharge standards, steady decrease of membrane cost and increased water reclamation needs, have given remarkable impetus to the extensive research and applications of MBR for biological wastewater treatment. A literature review shows that more than 3000 peer-reviewed English papers regarding MBR technology have been published. Furthermore, it was reported that more than 2500 MBR plants have been in operation worldwide with an annual growth rate of 10.5% during 2008–2013 [1]. Notwithstanding the significant progress of MBR technology, membrane fouling remains the primary hindrance for its universal and large scale applications. Membrane fouling would reduce system productivity, increase the energy requirement for gas scouring and frequency of cleaning which might shorten the membrane lifespan and result in higher replacement costs. Therefore, there is great interest in investigating the causes, characteristics, mechanisms and control measures of membrane fouling in MBRs.

Membrane fouling in MBRs is a result of the interactions between the sludge suspension and membrane unit [2–5]. For the given membrane and operational conditions, membrane fouling was directly affected by the sludge suspension. Sludge suspension is a very complex system, which is composed of varied salts, organic substances, colloids, cells and sludge flocs. All these substances could be the potential foulants affecting membrane fouling. Meanwhile, based on the relative contributions of foulants components to the total membrane fouling, several membrane fouling mechanisms, including pore clogging by colloidal particles, adhesion of foulants, formation of gel layer [6] and cake layer, cake layer consolidation [7], spatial and temporal changes of the foulant composition during the long-term operation [8] and osmotic pressure effect [9,10], have been proposed. Extracellular polymeric substances (EPSs) have been found to be key substances, which have complex interactions or relationships with all these membrane foulants and fouling mechanisms in MBRs (Fig. 1). Understanding of these interactions or relationships appears to be a fundamental route to understand membrane fouling and develop membrane fouling control strategies in MBRs. Despite many efforts to improve this understanding, the roles of EPSs in membrane fouling are still not well understood nor consistently reported. This situation may be attributed to the complex nature of membrane fouling and EPSs in MBRs. Meanwhile, studies have generally been limited to single treatment system. It is therefore necessary to summarize and analyze the past research progress. Nevertheless, no up-to-date review on this topic is yet available although several review papers have been devoted to summarize the effects of EPSs on the properties of activated sludge [11–15].

Bearing the information above, the review aims to provide an overview on the characteristics, roles and control strategies of EPSs regarding membrane fouling in MBRs. In the following, fundamental aspects of EPSs in MBRs will be reviewed. Effects of EPSs on membrane fouling in MBRs will be described and discussed. EPSs control in MBRs is also summarized. Finally, the main conclusions and the research needs are presented.

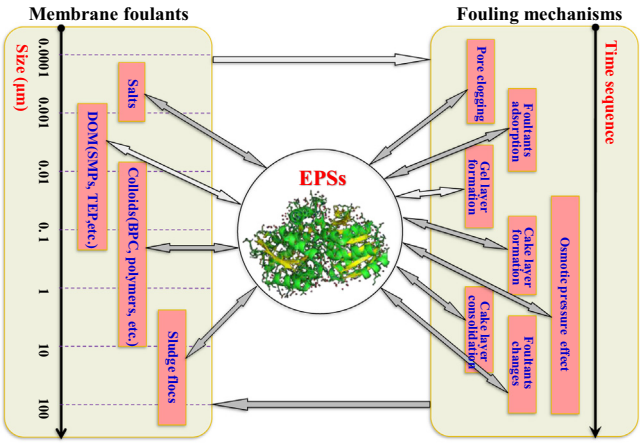

Fig. 1. Schematic illustration showing the interactions or relationships between EPSs and the membrane foulants, fouling mechanisms in MBRs.

2. Fundamentals of EPSs

2.1. Definitions and compositions of EPSs

Over 99% of microorganisms on earth live and grow within biosynthetic polymers (biopolymers) as aggregated forms. The term “EPSs” was therefore coined to describe these biopolymers. In the early studies concerning microorganisms, EPSs generally referred to “exopolysaccharides”, “extracellular polysaccharides” and “exopolymers” because polysaccharides were considered as the most abundant constituent parts at that stage. The definition of EPSs has been broadened with time. Geesey [16] defined EPSs as “extracellular polymeric substances of biological origin that participate in the formation of microbial aggregates”. In other words, EPSs are different classes of organic macromolecules present outside of cells or in the interior of microbial aggregates. Such a definition is generally limited to bound EPSs. Actually, EPSs can be in either bound or soluble form. A more broaden definition was then introduced to refer to both bound and soluble forms of biopolymers originated from microorganisms. In MBRs, soluble EPSs were considered to be same as soluble microbial products (SMP). The exact definition of what generates EPSs is not as easily addressed. For the sake of convenience, the accepted working