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Review

Exploiting extracellular polymeric substances (EPS) controlling strategies for performance enhancement of biological wastewater treatments: An overview

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HIGHLIGHTS

- EPS are of importance for microbial aggregates in biological wastewater treatments.
- EPS control can cause changes in microbial aggregates and system performance.
- EPS elevation has great potential in promoting microbial aggregates performance.
- EPS limitation has great potential in alleviating membrane fouling in MBRs.

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ABSTRACT

Extracellular polymeric substances (EPS) are present both outside of the cells and in the interior of microbial aggregates, and account for a main component in microbial aggregates. EPS can influence the properties and functions of microbial aggregates in biological wastewater treatment systems, and specifically EPS are involved in biofilm formation and stability, sludge behaviors as well as sequencing batch reactors (SBRs) granulation whereas they are also responsible for membrane fouling in membrane bioreactors (MBRs). EPS exhibit dual roles in biological wastewater treatments, and hence the control of available EPS can be expected to lead to changes in microbial aggregate properties, thereby improving system performance. In this review, current updated knowledge with regard to EPS basics including their formation mechanisms, important properties, key component functions as well as sub-fraction differentiation is given. EPS roles in biological wastewater treatments are also briefly summarized. Special emphasis is laid on EPS controlling strategies which would have the great potential in promoting microbial aggregates performance and in alleviating membrane fouling, including limitation strategies (inhibition of quorum sensing (QS) systems, regulation of environmental conditions, enzymatic degradation of key components, energy uncoupling etc.) and elevation strategies (enhancement of QS systems, addition of exogenous agents etc.). Those strategies have been confirmed to be feasible and promising to enhance system performance, and they would be a research niche that deserves further study.

Contents

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1. Introduction

The production of extracellular polymeric substances (EPS) is a general attribute of microorganisms in natural environments and occurs in prokaryotic and in eukaryotic microorganisms (Wingender et al., 1999a). EPS are a complex high-molecular-weight mixture of polymers, consisting of polysaccharides, proteins, humic acids, uronic acids, nucleic acids, lipids etc. (Flemming and Wingender, 2001b). The accumulation of EPS happens by a number of different mechanisms including excretion, secretion, cell lysis and sorption (Flemming and Wingender, 2001a). In biological wastewater treatments, microorganisms are in the form of microbial aggregates such as biofilms, sludge flocs and granules (Ni et al., 2009; Leng et al., 2015b; Jiang et al., 2016a), and the EPS are found to form as a layer around microbial aggregates to provide a three-dimensional protective matrix against external stress, described as "house of cells" (Flemming and Wingender, 2001a, b). It was reported that EPS were a main component in biofilms, and proportion of EPS varied from 50% to 80% (w/w) of total biofilms weight (Flemming and Wingender, 2010; Leng et al., 2015a; Meng et al., 2016). Many attempts have been made to investigate the chemical compositions and physicochemical properties of EPS, especially that of biofilms, sludge flocs and granules (Flemming and Wingender, 2001a, b; Sheng and Yu, 2006; Huang et al., 2008; Ni et al., 2009; Cao et al., 2015; Zhu et al., 2015). In recent years, the effects of EPS on properties and functions of microbial aggregates in biological wastewater treatments are paid much attention, and the EPS are proved to exhibit important roles in mass transfer (Characklis et al., 2013; Jiang et al., 2015), surface charge (Wang et al., 2006; Cao et al., 2016), flocculation, settleability, dewatering ability (Yang and Li, 2009; Peng et al., 2012; Jiang et al., 2016b), stability (Adav et al., 2008; Xiong and Liu, 2013), adhesion (Omoike and Chorover, 2006; Li et al., 2013), and formation (Zhang et al., 2014; Guo et al., 2016a; Huang et al., 2017) of microbial aggregates. Meanwhile, the occurrence or production of EPS was also reported to be responsible for membrane fouling in membrane bioreactors (MBRs), and some researchers have attributed the scaling of MBR modules to loosely bound EPS, and polysaccharides of EPS are key factor for membrane fouling (Drews et al., 2006b; Wang et al., 2009a). It should be noted that interaction of EPS with membrane surface is not well established till date, and there have been numerous theories or considerations reported in the literature which are often contradictory. Put simply, there is no doubt that EPS in microbial aggregates exhibit beneficial or detrimental role in biological wastewater treatment systems and it is expected that control of available EPS can cause changes in microbial aggregate properties and reactor performance.

Currently, several excellent reviews have highlighted roles of EPS, particularly that of microbial aggregates (Liu and Fang, 2003; Liu et al., 2004; Flemming and Wingender, 2010), in biological wastewater treatments (Sheng et al., 2010; More et al., 2014; Ding et al., 2015c; Li et al., 2015; Salama et al., 2016), in metal biosorption and bioremediation (Pal and Paul, 2008; Li and Yu, 2014), and in membrane fouling (Drews et al., 2006a; Malaeb et al., 2013; Lin et al., 2014c). However, considering the dual roles of EPS in biological wastewater treatments, there is still no consolidated report so far, which highlights EPS controlling strategies for enhancement of system performance. This review will present current state-of-the-art knowledge with regard to EPS basics and their brief roles for microbial aggregates in biological wastewater treatment systems, and special emphasis has been laid on EPS controlling strategies (limitation or elevation), which will provide useful information to scientists and engineers who work in this field.

2. Basics of extracellular polymeric substances (EPS)

2.1. Formation mechanisms of EPS

The formation of EPS by microbial aggregates has various origins including active secretion from microorganisms, cell surface material shedding, cell lysis, and sorption from environment (Wingender et al., 1999a; Liu and Fang, 2003). It is clear that the formation of EPS involves complicated mechanisms. EPS may be actively secreted by the living cells, and various specific pathways of biosynthesis and discrete export machineries involving the translocation of EPS across bacterial membranes to cell surface or into the surroundings have been described for bacterial proteins (for review see, e.g., Filloux et al., 1998) and polysaccharides (for review see, e.g., Jonas and Farah, 1998). Another mechanism of EPS release is spontaneous liberation of integral cellular components from outer membrane of Gram-negative bacteria which occurs by formation of the outer membrane-derived vesicles (Beveridge et al., 1997; Li et al., 1998). Release of cellular material by surface blebbing during normal growth may be the result of metabolic turnover