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Membrane cleaning in membrane bioreactors: A review

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ABSTRACT

Membrane bioreactors (MBRs) have been widely used in wastewater treatment and reclamation. Membrane cleaning is an essential part during the operation of MBRs since membrane fouling is an unavoidable problem. In past decades, with the in-depth understanding on membrane fouling, significant advances in membrane cleaning have been achieved. However, a comprehensive review on membrane cleaning in MBRs is still lacking. This paper attempts to critically review the recent developments of membrane cleaning. Firstly, the fouling and cleaning fundamentals are addressed, and then a comprehensive review on physical, chemical, and biological/biochemical cleaning is presented. The procedures of determining proper cleaning protocols for MBR systems are also proposed. Finally, the existing challenges and future research efforts are discussed in order to ensure the development of membrane cleaning toward a more effective and sustainable way in MBRs.

Contents

Abbreviations: AeMBR, aerobic membrane bioreactor; AnMBR, anaerobic membrane bioreactor; ATP, adenosine triphosphate; AOX, absorbable organic halogen; BFM, Berlin filtration method; BSA, Bovine serum albumin; CEB, chemically enhanced backflush; CIA, cleaning in air; CIP, cleaning in place; COD, chemical oxygen demand; COP, cleaning out of place; CP, concentration polarization; CSS, coarse suspended solids; DNP, dinitrophenol; DOC, dissolved organic carbon; DOTM, direct observation through the membrane; DTPA, diethylenetrinitrilopentaacetic acid; DVO, direct visualization on the membrane; EDTA, ethylene diamine tetraacetic acid; EIS, electrical impedance spectroscopy; EPS, extracellular polymeric substances; FS, flat-sheet; GAC, granular activated carbon; HF, hollow fiber; HFRB, hair and fiber reinforced biomass; MBR, membrane bioreactor; MLSS, mixed liquor suspended solids; MMV, magnetically induced membrane vibration; MT, multi-tube or tubular membrane (TM); PAC, powder activated carbon; PES, polyethersulfone; PSF, Polysulfone; PVDF, polyvinylidene fluoride; SRT, sludge retention time; THMs, trihalomethanes; NMR, nuclear magnetic resonance; PBS, phosphate buffered saline; SDS, sodium dodecyl sulfate; STP, sodium tripolyphosphate; TMP, trans-membrane pressure; UTDR, ultrasonic time-domain reflectometry; VFM, VITO fouling measurement; VHFM, vibrating hollow fiber modules; VSEP, vibratory shear enhanced process; XMI, X-ray micro-imaging

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1. Introduction

Membrane bioreactors (MBRs) have gained increasing popularity in municipal/domestic and industrial wastewater treatment, in particular in the places where footprint is limited and a high product water quality is demanded [1–4]. To date, there have been at least 50 individual MBR membrane suppliers and hundreds of large-scale MBR plants (with treatment capacity larger than 10,000 m^3/d) in operation worldwide [3,5]. In addition, MBR systems are expected to continuously increase in capacity and broaden in application areas due to more stringent regulations and water reuse initiatives [2,6,7].

Membrane cleaning is an essential part of operation in MBRs, which significantly influences membrane performance. It is well accepted that membrane cleaning can be categorized into physical cleaning and chemical cleaning [8]. Sustainable operation of MBRs relies on physical cleaning through relaxation or backflushing, or a combination of both, supplemented with periodic chemical cleaning in place (CIP) [9]. Physical cleaning removes loosely attached materials on membrane surfaces, generally termed 'reversible fouling', while chemical cleaning removes more tenacious materials often termed 'irreversible' fouling [5]. Biochemical/biological cleaning, which can be designated as the use of cleaning mixtures containing bioactive agents (enzymes or signal molecules) to remove membrane foulants from membrane surfaces [10,11], has been also developed in MBRs among research communities. Currently, numerous cleaning protocols and cleaners have been also provided by membrane and MBR suppliers [5].

However, membrane cleaning in MBRs has not been adequately addressed due to the following reasons: (1) membrane fouling, being a very complicated issue, has not been fully understood yet; (2) fouling and cleaning issues are specifically related to membrane properties, feed-biomass characteristics, and operating conditions; (3) cleaning protocols in full-scale MBRs are typically recommended from membrane manufacturers and/or MBR suppliers, and some cleaners are proprietary [12]; (4) the relations between academic researches and real applications are not tightly combined. In the past decade, significant advances in characterizing membrane fouling behaviors have been achieved, and several comprehensive reviews well documenting the fouling issue have been published [8,13–16]. The further understanding of membrane fouling is conducive to addressing membrane cleaning in MBRs. In recent years, a large number of papers regarding membrane cleaning in MBRs have been also published. Despite the growing number of specific studies, synthesis of the knowledge of membrane cleaning is scarce. In addition, the evaluation of various cleaning protocols and the comparison of different cleaners are lacking.

This review presents a state-of-the-art assessment of membrane cleaning based on the recent and relevant publications on the subject. After discussion of fouling and cleaning fundamentals, a comprehensive review on physical, chemical, and biological/biochemical cleaning is carried out. The procedures of determining proper cleaning protocols for specific MBR systems are also proposed. Finally, the existing challenges and future research efforts are discussed. With the increase of research efforts in this field, a detailed analysis and synthesis of past academic research achievements can contribute to establish a general understanding of membrane cleaning. Furthermore, a comprehensive review can be of interest to researchers, operators, and companies involved in MBRs. It will be also conducive to promoting the development of membrane cleaning toward a more effective and sustainable way.

2. Fundamentals of membrane cleaning

2.1. Overview of membrane fouling

2.1.1. Concentration polarization, external fouling, and internal fouling

During the past decade, Chang et al. [13], Le-Clech et al. [8], Meng et al. [14], Drews [15], and Wang et al. [16] carried out comprehensive reviews on the advances of membrane fouling by covering all fouling aspects, such as membrane materials, feed-biomass characteristics, and operating conditions. Herein, based on these publications, we summarize the major types of membrane fouling in MBRs. Membrane flux in MBRs can be affected by concentration polarization, external fouling, and internal fouling according to its locations relative to the membrane structure [5,17,18].

– **Concentration polarization**. Concentration polarization (CP) is defined as an accumulation of solutes or particles in a thin liquid layer adjacent to the membrane surface [19–21], which is an inherent phenomenon of membrane filtration. CP can increase resistance to liquid flow and thus reduce the permeate flux. CP is determined by convective flow driven by filtration and by the shear imparted at the CP boundary layer [22]. An increase of cross-flow velocity can alleviate CP.
– **External fouling**. The deposition of particles, colloids and macromolecules on the membrane surfaces leads to external