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Critical review and comprehensive analysis of trace organic compound (TOrC) removal with polyamide RO/NF membranes: Mechanisms and materials

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ABSTRACT

Trace organic compounds (TOrCs) have emerged as a critical concern for securing high-quality and safe water resources. Advanced water treatment using reverse osmosis (RO) and nanofiltration (NF) membranes has proven to be a promising technology for removing TOrCs. In this context, identifying the TOrC rejection mechanisms of RO/NF membranes is of paramount importance for the effective design of membrane processes and materials to improve the efficiency of TOrC treatment. However, the characteristic TOrC removal mechanisms of RO/NF membranes remain unclear, presumably due to the vast differences in the membrane structures and the limited number of TOrCs that have been investigated in past studies. Hence, the present article comprehensively reviews, analyzes and elucidates TOrC rejection mechanisms by characterizing key rejection-governing solute parameters for fully-aromatic polyamide-based tight RO/NF membranes (MWCO $\leq$ 200 Da) using the published rejection data for a large number of TOrCs (>300). We found that size exclusion and adsorption (and subsequent partitioning) via specific interactions play a dominant role in TOrC rejection by elucidating the key rejection-governing solute characteristics. In addition, this paper outlines up-to-date research on the fabrication of advanced membranes designed to improve TOrC removal performance. Based on this review, we propose future directions for reliably predicting and effectively enhancing the TOrC separation performance of RO/NF membranes.

1. Introduction

An emerging issue in the search for water resources that are reliable and safe is the presence of potentially hazardous trace organic compounds (TOrCs), which are difficult to remove from aqueous media [1–4]. TOrCs, which include pharmaceutically active compounds (PhACs) [3–6], personal care products (PPCPs) [3], pesticides [7], endocrine-disrupting chemicals (EDCs) and industrial wastewater by-products [3], can have a highly negative impact on human and ecosystem health even at low concentrations [5,8]. For example, the presence of antibiotics and antimicrobial agents in an aquatic environment can increase the antibiotic resistance of bacteria and reduce the antibiotic effect against pathogens [9]. Several lipophilic TOrCs also adversely affect human health by increasing the incidences of various diseases such as cancer and kidney failure [10].

TOrCs can be removed from water using biodegradation [11,12], adsorption [13–15], oxidation [16–18] and membrane separation. In particular, membrane separation has proven to be a promising technology for the removal and/or recovery of TOrCs because of its high removal efficiency and marginal solute deterioration [19–23]. Accordingly, the academic focus on membrane-based TOrC treatment technology has been rapidly growing, as evidenced by the fact that the number of annual publications on this subject doubled from 1999 to 2009 and again tripled from 2009 to 2019 (see Supplementary Material S1). Reverse osmosis (RO) and nanofiltration (NF) membranes have attracted particular interest due to their high rejection ability, with significant effort spent on elucidating the TOrC removal mechanisms of RO/NF membranes [3,4,19,20]. From this research, size exclusion,

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