Chapter 14
Membranes Technology Development and Challenges in Oily Wastewater Treatment: A Brief Review

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14.1 Introduction

Fast-growing industrial and agricultural show higher demand for fossil fuels and a variety of substances, which leads to serious environmental problems globally such as polluted oily wastewater (Zhang et al. 2016a). As one of the important contaminants in water, oil causes wastewater problems in environments (Mustafa et al. 2014). Decontamination of wastewater from industry is a key challenge from the environmental and ecological perspective (Sharma et al. 2018). This indicates that there is an increasing demand to treat oily wastewater to preserve the environment from its adverse impacts, and this situation has drawn the scientific community's interest (Modi and Bellare 2019).

Oily wastewater can be treated using conventional treatment methods such as gravity separation and skimming, dissolved air flotation, de-emulsification, coagulation, and flocculation. However, some shortcomings such as low efficacy, high operating costs, deterioration, and concern about decontaminating make the conventional treatment methods less attractive (Makki and Zghair 2014). Compared to conventional treatment methods, pressure-driven membrane filtrations such as microfiltration (MF), ultrafiltration (UF), and nanofiltration (NF) membranes are attracting worldwide attention due to their obvious performance. Nevertheless, though NF membranes have the benefit of maintaining low molecular weight species, the low-pressure MF and UF membranes have an advantage over NF membranes and can be utilized as submerged membranes (Chin et al. 2007).

Various research described the usage of polymeric membranes for wastewater treatment (Ong et al. 2014; Dzinun et al. 2017; Yaacob et al. 2020). Polyethersulfone

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and polyvinylidene fluoride (PVDF) are the two polymeric membranes that widely monopolize the membrane market despite membrane fouling badly controlling the polymeric membrane's progress because of their intrinsic hydrophobicity. On the other hand, ceramic membranes were unable to discover widespread use owing to their overprice and instability which jeopardizes the membrane's integrity. Hence, polymeric membranes are attracting much attention internationally (Shen et al. 2020).

Membrane filtrations are used to treat wastewater as the growing demand for clean water supply and water scarcity, in recent years (Hossein Razzaghi et al. 2014). Karakulski and Gryta (2017) reported that MF and UF membranes are frequently employed for oily wastewater treatment. These days, photocatalytic membrane reactors (PMRs) with UF membranes are used for the effective removal of organic compounds from water, and the use of UF membranes were cost-efficient for the treatment of oily wastewater because there is no need for chemical additives and environment-friendly (Rani et al. 2021). The treated wastewater can then be utilized in different ways such as by industry in utility plants, farming, and cleaning uses to prevent global water shortage (Rasouli et al. 2017).

14.2 Nanocomposite Membranes

The incorporation of nanoparticles into polymeric membrane matrixes produces nanocomposite membranes (Wen et al. 2019). The usage of titanium dioxide (TiO_2) or zinc oxide (ZnO) nanoparticles in membrane fabrication not only improves the morphology of the membrane but to aid in getting higher permeability. Furthermore, the extremely reactive oxygen species generated by TiO_2 aid oxide molecules to achieve full mineralization and add the antifouling characteristic to the membrane surface (Sakarkar et al. 2020). 3 wt% ZnO/polyvinyl chloride (PVC) nanocomposite membranes prepared by Rabiee et al. (2015) showed improvement in the flux recovery ratio from 69 to >90% indicating that the nanocomposite membranes were less susceptible to being fouled.

14.3 Photocatalytic Membranes

The fabrication of membrane using pure catalysts through methods such as coating or mixing of catalysts over a commercial membrane produces photocatalytic membranes (Iglesias et al. 2016) with photocatalytic ultraviolet (UV) responsive membranes and photocatalytic visible light responsive membranes are the two photocatalytic membranes widely used. For the functional membrane, the photocatalytic ultraviolet (UV) responsive membranes are activated by UV illumination and are mostly concentrating on TiO_2 or ZnO-based photocatalysts (Shi et al. 2019). ZnO has been recognized in photocatalysis and antifouling agent due to the high surface-to-volume ratio of ZnO nanoparticles which makes it an important nanostructure in many disciplines (Shen et al. 2020). Meanwhile, the non-toxicity, high decontaminating action, economical, chemically inactive, deterioration resistance, and stability make TiO_2 the frequently used photocatalyst in solar or artificial light-driven photocatalysis (Sharma et al. 2018).

Moghadam et al. (2015) reported that 20 wt% TiO_2/PVDF nanocomposite membranes exhibited improved antifouling properties under UV illumination in comparison to neat PVDF membranes. The flux recovery ratio of 98.1% has confirmed their antifouling property. The membrane hydrophilicity and porous structure also showed improvement because the UV illumination forms surface oxygen defects at the attaching site, which makes the dissociative adsorption of water more favorable at the membrane surface. Oily industrial wastewater was well treated using an 8 wt% TiO_2/PVDF-trifluoro ethylene (TrFE) nanocomposite membrane in a solar photoreactor as reported by Zioui et al. (2019). The reduction in the contact angle on the polymer matrix with the incorporation of TiO_2 nanoparticles is believed to allow for a higher contact between the nanoparticles and the oily wastewater.

14.4 Photocatalytic Membrane Reactors

Photocatalytic reaction and membrane separation are paired in photocatalytic membrane reactors (PMRs) to perform a transformation of chemicals process. The pairing improves the capabilities of classical photoreactors and membrane filtrations. The membrane enables an uninterrupted process in a system whereby the reaction during photocatalytic, the recovery of photocatalyst, and the separation of the products from the treated wastewater take place in a single step (Molinari et al. 2020). Generally, the two major arrangements for PMR are (i) slurry PMR whereby the reactor contains suspended catalyst particles in the feed solution, and (ii) immobilized PMR whereby the reactor is paired with immobilized catalysts in/on the membrane (immobilized PMR). The succeeding option is more promising since the TiO_2 photocatalyst recovering process can be shortened which eases the operating complexity and practical application expenses (Ong et al. 2014; Zhang et al. 2016b). The former option is associated with photocatalyst regeneration, low photocatalytic efficiency, high membrane resistance, and fouling (Rameshkumar et al. 2020).

A reactor system with TiO_2 suspended is reported to show improved performance than when deposited on the membrane surface. However, the slurry PMR involves a secondary process to free the catalyst from the treated water. In contrast, immobilization of TiO_2 in the membrane matrix can eliminate this additional process despite this approach leading to a decreasing surface area of the available sites for the reaction during photocatalytic. As such, evenly distributing TiO_2 nanoparticles within the membrane is required and can be accomplished through a single-step co-extrusion process. This is important to ensure a higher amount of TiO_2 nanoparticles be exposed to UV light and enable the reaction during photocatalytic to occur (Dzinun et al. 2017).

Soon after, a type of PMR with advantages such as inexpensive installation, energy efficiency, and ease of maintenance known as submerged photocatalytic membrane reactor (SPMR) emerged (Nguyen et al. 2020). In this integrated treatment process, the membrane plays a dual role in which the membrane acts as the support for TiO_2 photocatalyst as well as a physical selective barrier for the degraded products. TOC degradation and oil rejection as high as 80 and >90% were reported using 2 wt% TiO_2/PVDF hollow fiber membranes using SMPR (Ong et al. 2014).

14.5 Challenges

One of the challenges during the fabrication process of nanocomposite membranes includes the agglomeration of nanoparticles. Agglomeration can lead to a possible reduction in the antifouling ability of TiO_2 nanoparticles and a change in membrane topography and hydrophilicity as a result of the irregular distribution of particles in the membrane (Razmjou et al. 2012).

Challenges on photocatalytic UV-responsive membranes are the risk for the structure of the membrane to experience severe destruction by both reactive oxygen species (e.g., ·OH) and UV light and the impacts on the polymeric membranes are harsher. Apart from that, the solar energy usage efficiency is controlled by the TiO_2 or ZnO catalyst bandgap around 3–4% of the solar spectrum (UV region) while about 44–47% of visible light is left unexploited. Additionally, the photocatalytic performance of TiO_2 or ZnO-based catalysts is seriously limited by the rapid recombination of the photogenerated charges and demonstrate low photoactivity in the visible light region (Shi et al. 2019).

14.6 Conclusion

Oil pollution has brought substantial effects on the ecosystem, human security, and economic growth, which caught worldwide attention. With the laws and standards on environmental protection becoming stricter over time, the existing oily wastewater treatment technology can no longer satisfy the higher standard requirement. The development of improved oily wastewater treatment becomes more prominent to protect the environment. Nevertheless, the improved treatment methods are still facing some challenges which need to be overcome.

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