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Membrane technology enhancement in oil–water separation. A review

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HIGHLIGHTS

- Chemical composition and effects of oily wastewater
- Polymeric and ceramic membrane for wastewater oily treatment
- Effect of surface modification and effect of operating parameters of the membrane performance
- Combined systems with membrane separation and future outlook for removal of oily wastewater

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ABSTRACT

Membrane separation processes have become an emerging technology for the treatment of oily wastewater due to high oil removal efficiency and relatively facile operational process. This review will highlight the recent development of advanced membrane technology such as surface modification, addition of inorganic particles in polymer membrane and the development of ceramic membranes. Additionally, the effect of operating parameters on the membrane performance is discussed in detail. Future outlooks in oil–water membrane separation are also discussed to further broaden the research and development related to this technology.

Contents

Abbreviations: RO, reverse osmosis; MF, microfiltration; UF, ultrafiltration; NF, nanofiltration; BTX, benzene, toluene, and xylene; MWCO, molecular weight cut-off; COD, chemical oxygen demand; TOC, total organic carbon; MD, membrane distillation; PVDF, polyvinylidene fluoride; PSf, polysulfone; PES, polyethersulfone; PVP, polyvinylpyrrolidone; PEG, polyethylene glycol; LiCl H_2O, lithium chloride monohydrate; TiO_2, titanium dioxide; PTS, phosphorylated; SiO_2, silicon dioxide; Al_2O_3, Aluminum oxide; SZP, silica particles; TDS, total dissolved solid; TMP, transmembrane pressure; RF, Relative Flux; MPM, modified PVDF membrane; PM, PVDF membrane; GAC, granular-activated carbon; R-CTAB, cetyltrimethyl-ammonium bromide-modified polystyrene resin; MWCNTs, multiwalled carbon nanotubes; HMO, hydrous manganese dioxide; SZY, zirconia particles; PNIPAAm, poly(N-isopropylacrylamide); PPEGMA, (PNIPAAm)-blockpoly(oligoethylene glycol methacrylate); ATRP, atom transfer radical polymerization; GMA, glycidyl methacrylate; EDMA, ethylene glycol dimethacrylate; SDS, sodium dodecylsulfate; BOD, biochemical oxygen demand; TS, total solids; TSS, total soluble solids; CFV, cross flow velocity; PTFE, polytetrafluoroethylene; PPESK, poly(phthalazine ether sulfone ketone); NaOH, sodium hydroxide; Na, sodium; K, potassium; Ca, calcium; ANN, artificial neural network; ZrO_2, zirconium dioxide; NS, nano-scale; OPUS, optimized pre-treatment and unique separation; MBR, membrane bioreactor; R&D, research and development; PMR, photocatalytic membrane reactor.

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1. Introduction

The rapid industrial growth, such as in oil and gas, petrochemical, pharmaceutical, metallurgical and food industries, has led to the large production of oily wastewater. Necessity to treat the oily wastewater is an inevitable challenge. Furthermore, the rapid growths in population and economy have resulted in greater demand for clean water particularly in water-stressed areas [1]. Hence, the present surface resources will be no longer adequate to meet the needs of future generations.

One of the solutions for addressing this issue is the reuse of water which requires the adoption of advanced technologies, such as membrane technologies. The membrane technology market is witnessing an era of rapid growth due to continuous research and development in both academia and private industry. Additionally, the membrane technology has also been recently introduced as an efficient technique to separate oil/water mixture due to its ability to effectively remove the oil droplets when compared to the current conventional technologies [2–6]. There are several methods for the purification of oily wastewater, including conventional physical and chemical methods. Table 1 shows chemical and physical methods for the oily wastewater treatment with advantages and disadvantages. Adsorption (activated carbon, organoclay, copolymers, zeolites and resins), sand filter, cyclones and evaporation are the physical treatments and oxidation, electrochemical process, photocatalytic treatment, Fenton process, ozone treatment, ionic liquids at room temperature and demulsifier are the chemical treatment methods. These conventional methods have their own drawbacks, such as, high cost, using toxic compounds, large space for installation and generation of secondary pollutants. Keeping these drawbacks in view, membrane separation processes serve as an emerging technology in the 21st century. However, the major problem attacking the membrane separation processes is membrane fouling. The membrane fouling still remains one of the most technical challenges in the separation industries.

Hence, in this article, recent advances in the membrane technology for oil–water separation will be reviewed in detail. Additionally, the combined method used to treat oily wastewater will be also discussed.

2. Oily wastewater compounds

The organic compounds in oily sludge are classified into 4 different groups according to their chemical structure. These are aliphatic, aromatics, nitrogen sulfur oxygen (NSO) containing compounds, and asphaltenes [23,24]. Alkanes, cycloalkanes, benzene, toluene, xylenes, naphthalene, phenols, and various polycyclic aromatic hydrocarbons (PAHs) (e.g., methylated derivatives of fluorine, phenanthrene, anthracene, chrysene, benzofluorene, and pyrene) are present in oily sludge water. Overall, aliphatics and aromatic hydrocarbons usually account for up to 75% of PHCs in oily sludge [25,26]. The heterocyclic compounds like naphthenic acids, mercaptans, thiophenes and pyridenes, as NSO compounds, are dominant in oily sludge [26]. The asphalt and resin are more in concentration as compared to NSO compounds. The nitrogen (N) content accounts for less than 3% sulfur content molecule 0.3–10% and oxygen content molecule is usually less than 4.8% [26].

A wide range of contaminants at varied concentrations are discharged together with oil. The high amount of dissolved oxygen in the affects leads to the decreased productivity of algae is a very important link in the food chain [27]. As known earlier, 2 mg/L is the required amount of oxygen to sustain normal life in an aquatic environment. The discharge of oily wastewater containing high levels of organic matter into water bodies results in an excess consumption of oxygen by the

Table 1
Different chemical and physical methods for oily wastewater removal.

Methods for purification	Advantages	Disadvantages	Ref.
Solvent extraction	Efficient method and very fast process	High cost and environmentally unfit, heavy metals cannot be removed by this process	[7]
Centrifugation	Easy to process, no need of any solvent and environmentally safe	Large among of energy required, economically unfit and lower size molecules difficult to settle down.	[8]
Forth flotation	Easy to apply and less energy required	Highly viscous oily wastewater cannot be offered to this process	[9]
Ultrasonic irradiation	Fast and effective, no need any chemicals	Heavy equipment cost, unable to treat heavy metals	[10]
Surfactant EOR	Easy to process and limited application in heavy metals	High cost, surfactant should be toxic, alternate process required to remove surfactant and economically costly	[11]
Freeze/thaw	Short treatment process and suitable for cold regions	Less effective and coastally process	[12]
Microwave irradiation	Very fast and efficient and no need of chemical addition	Specially designed equipment, heavy costly and not effective for large scale process	[13]
Electrokinetics	No need to chemical addition and fast process	Process is not easy and less effective	[14]
Pyrolysis	Large treatment capacity, fast and effective	High capital, maintenance and operating cost	[15]
Incineration	Rapid and complete removal of PHCs in oily sludge	High cost of equipment and alternate process is required to remove ash	[16]
Stabilization/solidification	Fast and efficient to produce PHC stabilized compounds, low cost and capture the heavy metals	Loss of recyclable energy and less effective in process	[17]
Oxidation	Rapid and complete removal of PHCs in oily sludge.	Large amount of chemical required, high cost and environmentally unfit	[18]
Land farming	Low cost and do not need much maintenance and applicable to large quantity also	Sand pollution and underground water pollution	[19]
Landfill	Less cost and large treatment capacity	Very slow process and required more place	[20]
Biopile/compositing	Large treatment capacity, low cost, faster and less area required for the process	Applicable in cold condition	[21]
Bioslurry	Fastest degradation approach, great PHC removal	High cost and applicable to small scale	[22]