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Advancing pharmaceutical wastewater treatment: A comprehensive review on application of catalytic membrane reactor-based hybrid approaches

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ABSTRACT

Pharmaceutical wastewater presents a concerning array of toxic chemicals, necessitating proper treatment and disposal to safeguard human health and the environment. These chemicals, including active pharmaceutical ingredients, antibiotics, solvents, and organic compounds, exhibit toxicity, flammability, and carcinogenicity, posing risks to living beings and ecosystems. Contaminants such as surfactants, emulsifiers, residual drugs, and metabolites further exacerbate the complexity of pharmaceutical wastewater. Conventional treatment technologies, such as activated carbon adsorption, oxidation processes, membrane filtration, and biological treatment, suffer limitations in effectively removal or neutralizing hazardous substances for the safe disposal of pharmaceutical wastewater if implemented individually. In particular, combining photocatalysis with membrane technology demonstrates promising benefits, enhancing degradation efficiency and reducing membrane fouling. Membrane catalytic reactors (MCRs) integrated with advanced oxidation systems, viz. photocatalysis, Fenton-based processes, ozonation, persulphate generation, and the electrocatalytic process, can degrade pollutants and realize their physical separation. The present review manuscript comprehensively discusses detailed mechanisms, performance, influencing factors, and generation of catalytic radicals for removing organic pollutants in hybrid MCRs to improve water quality and safeguard ecosystems from wastewater.

Abbreviations: APAP, acetaminophen; ACF, activated carbon fiber; AOPs, advanced oxidation processes; AMP, ampicillin; AnMBR, anaerobic membrane bioreactors; AQY, apparent quantum yield; AZM, azithromycin; BF-MBR, biofilm membrane bioreactor; BOD, biological oxygen demand; BDD, boron-doped diamond; CF, carbon fiber; CQDs, carbon quantum dots; CMs, catalytic membranes; CBZ, carbamazepine; CEX, cephalexin; CMF, ceramic membrane filtration; COC, chemical oxygen concentration; COD, chemical oxygen demand; CAP, chloramphenicol; CIP, ciprofloxacin; CT, contactor-type; DT, distributor-type; DOX, doxycycline; EFCM, electro-Fenton catalytic membrane; EF, electro-Fenton; EO, electro-oxidation; EDUF, electrodialysis and ultrafiltration; ED, electrodialysis; EE/O, energy per unit order; ET, extractor-type; FBR, fluidized-bed Fenton; FO, forward osmosis; GPMs, geopolymeric membranes; HRT, hydraulic retention time; MMW, magnetic mining waste; MBR, membrane-incorporated bioreactors; MCRs, membrane catalytic reactors; MOF, metal-organic framework; MF, microfiltration; MICM, molecularly imprinted catalytic membrane; NF, nanofiltration; OFL, ofloxacin; OTC, oxytetracycline; PS, peroxydisulfate; PMS, peroxymonosulfate; PhACs, pharmaceutically active compounds; PEC, photo-electrocatalytic; PM, photocatalytic membrane; PMR, photocatalytic membrane reactor; PNF, photocatalytic nanofiltration; POF, photocatalytic optical fibers; PSf, polysulfone; PVDF, polyvinylidene fluoride; QY, quantum yield; RO, reverse osmosis; SRT, solid retention time; SDZ, sulfadiazine; SMZ, sulfamethoxazole; TCH, tetracycline hydrochloride; TC, tetracycline; ZTM-T, Ti-based catalytic membranes; TiO_2-HAP, titanium dioxide-doped hydroxyapatite; TDS, total dissolved solid; TOC, total organic carbon; TMP, trimethoprim; UF, ultrafiltration; UV, ultraviolet; ZO, zinc oxide.

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