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Review

Technologies for removing pharmaceuticals and personal care products (PPCPs) from aqueous solutions: Recent advances, performances, challenges and recommendations for improvements

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ABSTRACT

In recent years, the removal of pharmaceutical and personal care products (PPCPs) from aqueous solutions has been gaining a lot of attention from researchers throughout the world. This is particularly due to the concern about their potential hazards and toxicities, as they are classified as emerging contaminants. Thus, there is an increasing need to investigate removal technologies for PPCPs at a deeper and more holistic level. This review aims to provide the latest developments in removal technologies for PPCPs. It first succinctly describes the types, characteristics, and hazards of PPCPs on the environment and human health. It then comprehensively covers a wide range of technologies for removing PPCPs from aqueous solutions, comprising the adsorption process (using carbon-based adsorbents, plant biomasses, clay and clay minerals, silica-based adsorbents, zeolite-based adsorbents, polymers and resins, and hybrid adsorbents), advanced oxidation processes (AOPs) (photocatalysis, Fenton or photo-Fenton or electro-Fenton, ozonation, ultrasonication, electrochemical oxidation, persulfate oxidation), membrane separation processes (ultrafiltration, nanofiltration, reverse osmosis), biodegradation processes (bacteria, fungi, and algae), and hybrid treatment (adsorption-AOP, AOP-membrane, membrane-biodegradation, and others). According to the specific experimental conditions, the reported removal efficiencies for adsorption, AOPs, membrane processes, biodegradation processes and hybrid treatment were 40–100%, 40–100%, 3–100%, 14–100% and 5–100%, respectively. This review paper also highlights the challenges in this field of research, particularly incomplete removal of certain PPCPs, high costs of some treatment technologies and generally insufficient understanding on the removal kinetics and mechanisms of PPCPs.

Abbreviations: ANN, Artificial neural network; AOA, Ammonium oxidizing archaea; AOB, Ammonium oxidizing bacteria; AOPs, Advanced oxidation processes; ASP, Activated sludge process; BDA, Butanediamine; COD, Chemical oxygen demand; CW, Constructed wetland; DO, Dissolved oxygen; DSPM-DE, Donnan steric pore model with dielectric exclusion; Fe-FeOOH, Iron (III) oxide-hydroxide; HLR, Hydraulic loading; HOMO, Highest occupied molecular orbital; HPLC-MS/MS, High-performance liquid chromatography-tandem mass spectrometry; HRT, Hydraulic retention time; HSSF, Horizontal subsurface flow; LCA, Life cycle assessment; LC-MS/MS, Liquid chromatography-tandem mass spectrometry; log K_{oc}, Soil organic carbon sorption coefficient; log K_{ow}, Octanol-water partition; LUMO, Lowest unoccupied molecular orbital; MC, Monte Carlo; MMM, Mixed matrix membrane; MMT, Montmorillonite; MTBE, Methyl tertiary butyl ether; MWCO, Molecular weight cut-off; NMA, *N*-methylacetamide; OLR, Organic loading; PAC, Powdered activated carbon; PHBV, Poly-3-hydroxybutyrate-*co*-hydroxy valerate; pK_a, Dissociation constant; PPCPs, Pharmaceutical and personal care products; PPD, p-phenylenediamine; QSAR, Quantitative structure–activity relationship; SBRs, Sequencing batch reactors; SiNP, Modified silica nanoparticle; SPH, Solid-phase denitrification; TOC, Total organic carbon; UASB, Up-flow anaerobic sludge blanket; WWTPs, Wastewater treatment plant.

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This review offers recommendations for future works to further advance the technical performances to eventually realize the wider application of these technologies at the industrial scale.

Contents

1. Introduction

Water pollution has been a persistent environmental problem as a result of development, industrialization and urbanization. A myriad of water pollutants consisting of pharmaceuticals and personal care products (PPCPs), heavy metals, pesticides, excessive nutrients, radioactive substances, as well as faecal waste containing harmful pathogens have been detected in various waterbodies [1]. The water pollutants also contaminate other phases of the environment especially the sediments through various transport processes [2]. These pollutants threaten public health and the health of the ecosystems due to their potential deleterious effects, particularly on the gastrointestinal, nervous, endocrine and reproductive systems in addition to the carcinogenic risks certain pollutants, such as polychlorinated biphenyls, pose [3]. As such, water pollution and its remediation have always been at the centre of research interest.

PPCPs have come to the attention of the scientific community due to their increasing presence in various spheres of the environment particularly surface water, groundwater and soil [4]. They are regarded as emerging contaminants as their presence in the environment has not been adequately monitored despite their potential toxicity to the ecosystem and humans [5]. PPCPs constitute a diverse array of chemicals commonly used on animals and humans for the treatment of diseases, maintenance of hygiene and beautification, all of which are intended to improve the quality of life [6]. Examples of PPCPs are antibiotics, blood lipid regulators, hormones, anti-inflammatory drugs, insect repellents, sunblock and disinfectants [7].

As PPCPs are used for various purposes and are often accessible to consumers, it has been extremely challenging to control their supply to the consumers, their amounts of usage and how they are being used [5]. These invariably lead to their entry into the environment. PPCPs have been detected in waste streams and sewage at various concentrations [8]. Conventional wastewater and sewage treatment processes have not been designed to adequately remove PPCPs from the waste streams [9]. In conventional wastewater treatment plants (WWTPs), PPCPs are usually removed during secondary treatment but numerous studies have pointed to their presence in water even after secondary treatment [7,10].

Diclofenac and carbamazepine had been detected in the effluents of two conventional WWTPs in Spain while caffeine,