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Review

Treatment technologies for emerging contaminants in water: A review

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HIGHLIGHTS

- Despite significant research in ECs removal, significant knowledge gaps remain.
- Phase-change, biological, AOP technologies, most common for removal of ECs in water.
- Phase-change processes creates a challenge due to the concentrated waste streams.
- Most research studies are laboratory scale, limited guidance for process scale-up.

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ABSTRACT

In recent years, the presence of a group of contaminants, termed as emerging contaminants (ECs) has been recognized as significant water pollutants that have adverse effects on human and wildlife endocrine systems. Natural attenuation and conventional treatment processes are not capable of removing these micropollutants which are reported to bioaccummulate in macro invertebrates, other organisms in the aquatic food web and humans. An in-depth review of the state-of-the-art technologies available to remove emerging contaminants (ECs) in water was undertaken. The results of the review show that the majority of the research in recent years has focused on using phase-changing processes, including adsorption in different solid matrices and membrane processes, followed by biological treatment and advanced oxidation processes. This paper focuses on the type of EC being removed, the conditions of the process and the outcomes achieved. The main trends in the field are also highlighted along with perceptive comments and recommendations for further developments as well as the identification of the current knowledge gaps and future research directions related to the application of these technologies for water treatment and restoration.

Contents

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1. Introduction

Investigations into water quality commonly focus on nutrients, microbial pollutants, heavy metals, and priority pollutants. However, recent research reveals the presence of a multitude of organic contaminants that significantly affect water quality. These contaminants originate from diverse sources and typically in concentrations that range from ng L^{-1} to μg L^{-1} [1]. This group of contaminants, termed as emerging contaminants (ECs), are chemical compounds that are commonly present in water, but are only recently being recognized as significant water pollutants. Emerging contaminants are natural or synthetically occurring substances not commonly monitored in the environment and having known or suspected undesirable effects on humans and the ecosystem. This group include compounds such as pharmaceutical and personal care products (PPCPs), pesticides, and hormones that have adverse effects on human and wildlife endocrine systems. Therefore, these are included in the endocrine disrupting compounds (EDCs) group. Natural attenuation and conventional treatment processes are not capable of removing these micropollutants from wastewater and surface and drinking water and are reported to bioaccummulate in macro invertebrates, other organisms in the aquatic food web and humans [2–4].

The significance of this issue needs to be viewed in the context of increasing detrimental impacts of climate change on rainfall patterns and compounded by limited opportunities to further expand conventional water sources to enhance urban water supplies [1,5]. Unfortunately, the variety of ECs in water has increased over the past years, mainly as a result of advances in analytical techniques, resulting in its detection at very low concentrations in water samples [5–9]. Successful water reuse not only depends on availability, but appropriate treatment is also essential. Although in-depth scientific investigations of pollutants such as nutrients, hydrocarbons, and heavy metals in stormwater and wastewater have been undertaken, only a very limited number of systematic studies have reported on the presence of ECs and even fewer related to the identification of appropriate treatment. Consequently, sustainable reuse of water contaminated with ECs is an ongoing challenge.

It is imperative that before the detrimental impacts of climate change compel communities to reuse water without adequate safeguards, good practices underpinned by scientifically robust policies are adopted to mitigate potential human health and environmental risks. Inability to appropriately manage ECs in water, risks squandering the opportunity to gainfully use one of the last available and largely uncommitted water resource for many urban areas. Identifying the technological trends and knowledge gaps in relation to the removal of emerging contaminants in water is a priority that must be addressed in order to inform the scientific community towards the adoption of best practices to ensure the use of safe drinking water for the community. Accordingly, the primary focus of this study was to undertake an in-depth review of state-of-the-art processes currently available for removing emerging contaminants so that this alternative water source can be used without creating potential human or ecosystem health risks and the identification of current knowledge gaps and to determine future research directions.

2. ECs in water: causes, effects and analysis

The number of chemical groups constituting ECs is large and continues to grow as new chemicals are identified to be part of this classification. In their biannual review of ECs in water, Richardson and Ternes [10] include a wide variety of compounds to the EC group, including sucralose and other artificial sweeteners, nanomaterials, perfluorinated compounds, drinking water and swimming pool disinfection by-products, sunscreens and UV filters, flame retardants, benzotriazoles and benzothiazoles, siloxanes, naphthenic acids, musks, algal toxins, and ionic liquids and prions. With advancements in the chemical industry, the variety of compounds being released to the environment which are potentially harmful to humans and the ecosystem over the long-term is expected to grow significantly over the years [11,12]. In recent years, researchers have shown an increased interest in monitoring ECs, but little agreement exists on the list of substances that should be monitored [13].

2.1. Pharmaceuticals

Pharmaceuticals are an important group of ECs and their presence in drinking water has generated significant concerns regarding the risk of estrogenic and other adverse effects on humans and fauna [14]. Approximately 3000 different substances are estimated to be used as pharmaceutical ingredients, including painkillers, antibiotics, antidiabetics, beta blockers, contraceptives, lipid regulators, antidepressants, and impotence drugs. Only a small subset of these ECs has been investigated in environmental studies. The large-scale use of pharmaceuticals has also increased their presence in surface water, groundwater, wastewater and stormwater runoff in urban areas [15–18].

2.2. Antibiotics, biocides, and pesticides

The major concerns in relation to antibiotics, biocides, and pesticides, is the development of bacterial resistance after their release into the environment [19–21] and the detrimental effect on the biodegradation of plant materials, which disrupts the primary food chain in aquatic ecosystems [10]. The term “pesticide” refers to chemicals used for agricultural purposes, whereas the term “biocide” refers to chemicals used in urban environments [22]. Biocides are mainly used in bituminous roof sealing membranes and external facades or for grass management and weed control. During rain events, biocides and pesticides are incorporated in surface and groundwater via stormwater runoff [23–29].