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Occurrence, impacts and removal of emerging substances of concern from wastewater

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HIGHLIGHTS

- Emerging substances of concern (ESOC) are present in water resources worldwide.
- ESOC are mutagens and carcinogens with effect on both aquatic organisms and humans.
- Conventional wastewater treatment processes are ineffective at ESOC removal.
- Membrane bioreactor technology can remove ESOC but has fouling limitation.
- Granulation technology and nano-remediation have strong potential for ESOC removal.

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ABSTRACT

Emerging substances of concern (ESOC) have recently been detected in water resources worldwide, raising human and environmental health concerns. This paper provides an overview of the different classes of ESOC, their impacts, extent of removal by conventional wastewater treatment technologies such as activated sludge process, and documented results on emerging innovative technologies. Conventional wastewater treatment plants exhibit some limitations with respect to ESOC removal since ESOC were not considered in their initial design. Although, advanced oxidation processes using ozone with other oxidation agents such as UV (ultraviolet), hydrogen peroxide, titanium oxide, etc., prove effective, they are cost prohibitive and can produce by-products with unknown toxicity. Early results for emerging biological technologies such as membrane bioreactors (MBRs) and granulation biotechnology indicate very promising ESOC removal. However, membrane fouling is the main drawback of MBRs as it significantly reduces membrane performances and membrane life resulting in an increase in maintenance and operating costs. The main drawback of granulation technology is the deterioration in granule stability under long-term operation and lack of a successful pilot- or full-scale application. Thus, further research is required to abate membrane fouling in MBRs and enhance long-term granule stability in granular systems. The technological revolution offered by nano-materials (NMs) provides a new potential for ESOC removal through nano-remediation. Effective removal of ESOC has been reported using nano-adsorbents, nano-membrane filters and photocatalysts. However, the environmental fate and the toxicological impact of NMs need to be assessed for their potential toxicity and bioaccumulation.

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1. Introduction

The purpose of wastewater treatment is to remove contaminants (pollutants) found in wastewater to acceptable levels before discharging the treated effluent into the environment. This is to prevent human health issues and ecological hazards arising from untreated wastewater. Over the past century, conventional technologies employed in treating municipal wastewater include: trickling filter, activated sludge process, waste stabilization ponds, or innovative modifications of these technologies. These technologies are effective at removing suspended solids, organics and pathogens, partial removal of nutrients (nitrogen and phosphorus) and heavy metals. However, they are ineffective at removing a group of recently identified substances in wastewater, collectively called emerging substances of concern (ESOC), including; pharmaceuticals, pesticides, personal care products (PCPs), surfactants, steroids and hormones, flame retardants and plasticizers, etc.

ESOC have frequently been detected in domestic wastewaters and in almost every aquatic environment in North America, Europe, Asia and Africa in recent years (Guerra et al., 2014; Chen et al., 2006; Richardson et al., 2005a; Sorensen et al., 2015; Yan et al., 2015; Liu and Wong, 2013). One study showed that pharmaceuticals and PCPs were present in 80% of 139 US streams (Onesios et al., 2009). Another study indicated that pharmaceuticals and PCPs were found to be present at high loads reaching 80 kg/d in raw sewage in South Wales in UK (Kasprzyk-Hordern et al., 2008). In Canada, a recent Environment Canada study identified 165 different ESOC found in Canadian water samples, and found that treated drinking water was contaminated by excreted drugs (Crowe, 2014).

The fate and transport of many ESOC in different environmental media including soil and sediments has became a major concern (Petrovic et al., 2008), especially with the lack of regulations on the concentration limits of ESOC in the environment whether by the US or European Union (Bolong et al., 2009; Luo et al., 2014a; Milić et al., 2012). Only few countries have started regulating some of these micro-pollutants. Environment Canada, for instance, has recognized nonylphenol and nonylphenol ethoxylates as toxic substances and set limits for their concentrations in the aquatic environment, with guideline values of 1.0 μg/L for freshwater and 0.7 μg/L for marine (CCME, 2002). In the United States, 11 disinfection by-products (DBPs) are regulated (Richardson et al., 2007). Despite this positive development, a large number of other unregulated DBPs exist. And recently, the United States Environmental Protection Agency (USEPA) published a new contaminant candidate list-3 (CCL-3) to be considered for potential regulation under the Safe Drinking Water Act. The CCL-3 contains 104 chemicals including, among others: pharmaceuticals, pesticides and their metabolites, perfluorinated compounds, hormones, and DBPs (Richardson, 2010). In the same regard, there is a ban on perfluorooctanoic acid (PFOA) from consumer products in Norway since 2013 (European Commission, 2011). Similarly, there is a health-based guide value for safe lifelong exposure of PFOA for drinking water in Germany of 0.3 μg/L (Wilhelm et al., 2010).

On the global scale, many ESOC have been banned under the Stockholm Convention including aldrin, endrin, alpha-hexachlorocyclohexane, beta-hexachlorocyclohexane, pentachlorobenzene, Chlordecone (kepone), polychlorinated Biphenyls, etc. (UNEP, 2010). Under the same convention, the use of other ESOC have been restricted, e.g. DDT (1,1,1-trichloro-2,2-bis (4- chlorophenyl)ethane), perfluorooctane sulfonic acid including its salts, and perfluorooctane sulfonyl fluoride. However, considering the unavailability of adequate data, the World Health Organisation (WHO) is yet to include most ESOC (e.g. pharmaceuticals) in its guidelines for drinking-water quality (WHO, 2011).

The aim of this paper is to identify different classes of ESOC, outline their adverse impacts on human and environmental health, discuss the potential removal processes and identify further research needs.