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Review

Understanding the sorption and biotransformation of organic micropollutants in innovative biological wastewater treatment technologies

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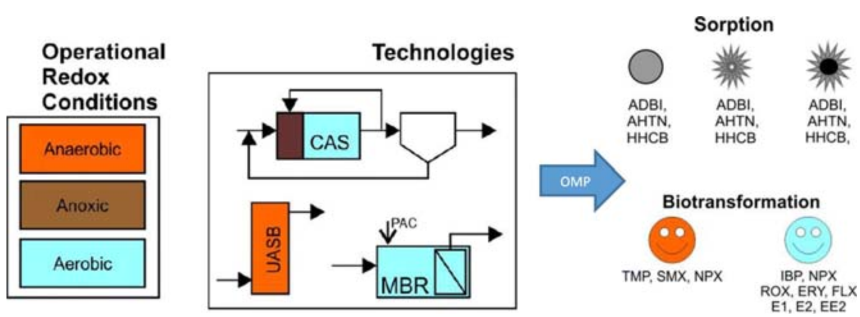
HIGHLIGHTS

- Organic micropollutant (OMP) removal is driven by sorption and biotransformation.
- Removal is influenced by several operational parameters and the OMP characteristics.
- Reactor hydrodynamics and biomass characteristics determine the sorption efficiency.
- Cometabolic OMP biotransformation is influenced by the primary substrate activity.
- The addition of activated carbon enhances OMP sorption and biodegradation.

GRAPHICAL ABSTRACT



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ABSTRACT

New technologies for wastewater treatment have been developed in the last years based on the combination of biological reactors operating under different redox conditions. Their efficiency in the removal of organic micropollutants (OMPs) has not been clearly assessed yet. This review paper is focussed on understanding the sorption and biotransformation of a selected group of 17 OMPs, including pharmaceuticals, hormones and personal care products, during biological wastewater treatment processes. Apart from considering the role of "classical" operational parameters, new factors such as biomass conformation and particle size, upward velocity applied or the addition of adsorbents have been considered.

It has been found that the OMP removal by sorption not only depends on their physico-chemical characteristics and other parameters, such as the biomass conformation and particle size, or some operational conditions also relevant. Membrane biological reactors (MBR), have shown to enhance sorption and biotransformation of some OMPs. The same applies to technologies bases on direct addition of activated carbon in bioreactors.

The OMP biotransformation degree and pathway is mainly driven by the redox potential and the primary substrate activity. The combination of different redox potentials in hybrid reactor systems can significantly enhance the overall OMP removal efficiency. Sorption and biotransformation can be synergistically promoted in biological reactors by the addition of activated carbon. The deeper knowledge of the main parameters influencing OMP removal provided by this review will allow optimizing the biological processes in the future.

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Contents

1. Introduction

The conception of wastewater treatment is moving towards a circular economy approach in the last years, in which the process economy should be balanced with the protection of natural resources and environmental sustainability (WWAP, 2017). Even though, nowadays still most wastewater treatment plants (WWTPs) are based on conventional biological treatment processes designed for the removal of organic matter and nutrients through the combination of anaerobic, anoxic and aerobic bioreactors, as well as complementary physico-chemical separation units. These classical approaches have achieved convincing results in terms of organic matter and nutrients removal. However, these installations are facing a number of challenges mostly derived from the need of reducing their footprint both physically (less land area required) and, especially, from an environmental point of view (less energy consumption, less sludge production, fewer pollutants and greenhouse gasses emissions, etc.). The need to advance in resource recovery such as nutrients or reclaimed water completes this challenging scenario.

In this context, the problem derived from the presence of chemicals of emerging concern, such as organic micropollutants (OMPs) including pharmaceuticals, hormones, and personal care products, has been widely assessed in different environmental water compartments (sewage, surface, ground and drinking waters) all around the world along the last decades. The effluent discharges from WWTPs constitute the main source of OMPs into the environment (Carmona et al., 2014; Luo et al., 2014; Clara et al., 2011; Monteiro and Boxall, 2010). It has been shown that even conventional technologies are able to remove efficiently some OMPs (Belhaj et al., 2015; Nakada et al., 2006; Carballa et al., 2004), although there is still a significant group of compounds with a recalcitrant behaviour (Clara et al., 2011; Kim et al., 2007; Carballa et al., 2004).

Some innovative biological treatment technologies have demonstrated important benefits in terms of operational costs and removal efficiencies for conventional pollutants (organic matter, nutrients or solids). Studies about anammox-based processes, hybrid systems combining different redox conditions, moving bed biofilm and packed bed reactors and anaerobic treatments applied to the water line have been recently n published (Bilal et al., 2017; Luo et al., 2014; Vázquez-Padín et al., 2014; Kartal et al., 2013; Ettwig et al., 2008). However, there is still a lack of knowledge about their capacity for removing OMPs.

There are already legal initiatives that support the importance of broadening the number of pollutants when assessing the quality of water. The European Union has specifically included 12 OMPs in the watch list for emerging water pollutants under the 2015's Water Framework Directive (WFD). These micropollutants should be monitored during three years in order to consider their future inclusion in the list of priority substances and to determine their respective discharge limits in function of their possible toxic, estrogenic and mutagenic effects. This should be considered as an indicator of the need to include the removal of OMPs as a parameter for WWTPs optimization, besides other variables normally considered (e.g. efficiency of macropollutant removal, reduction of the operational costs, etc.).

The first approach to consider the removal of micropollutants in new WWTP projects is to more deeply understand their removal mechanisms, including the influence of the operating conditions, as well as the role of the microbial community on their sorption and biotransformation. The authors have a long-term experience of >15 years in research on the removal of OMPs in different biological processes, including from more conventional to advanced technologies. The results have shown that the combination of anoxic and aerobic conditions commonly applied in conventional denitrification processes leads to the removal of several OMPs, such as ibuprofen (IBP), naproxen (NPX), celestolide (ADBI) or roxithromycin (ROX) (Suárez et al., 2010). The application of an anaerobic pretreatment step has shown to broaden the number of OMPs that are partially biotransformed (Alvarino et al., 2014). The use of membrane bioreactors (MBR) allows operation at higher biomass concentrations and sludge retention time (SRT), which implies a higher microbial diversity. According to Reif et al. (2011), this explains the improved removal of the pharmaceuticals IBP and NPX in an MBR compared to a conventional activated sludge (CAS) unit. These results suggest that treatment strategies based on the combination of different redox potentials and on the application of high SRT (by the use of membranes, supports or granular biomass) allow reaching higher OMP removal efficiencies for most of the OMPs studied.

This paper is a review of the behaviour of OMPs during biological wastewater treatment processes, focussing on the factors influencing sorption and biotransformation as the main OMP removal mechanisms. It is based on previous experiments on OMP removal with different technological configurations, moving from more conventional processes, such as: i) an aerobic conventional activated sludge (CAS) unit of 2 L (Alvarino et al., 2014) and ii) an upflow anaerobic sludge blanket (UASB) of 4.5 L (Alvarino et al., 2014); to more advanced integrated systems: iii) an autotrophic nitrogen removal process (ELAN®) of 200 L (Alvarino et al., 2015), iv) a hybrid anaerobic-aerobic membrane process (AnHMBR) of 176 L (Alvarino et al., 2016a) and v) a sequential batch reactor coupled to an MBR conceived for operation with direct addition of powdered activated carbon (PAC) (SeMPAC®) of 48 L (Alvarino et al., 2016b). The main characteristics of these five systems are summarized in Table 1 and in more detail described in