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Improving the control of pharmaceutical compounds in WWTPs through the addition of new waste-based activated carbons

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Abstract: Pharmaceutical compounds (PhCs) are concerning the regulators and the general public because very little is known about their long-term and synergistic health-environmental effects. As some of these compounds are resistant to conventional wastewater treatment plants (WWTPs) though prone to adsorption, the addition of powdered activated carbon (PAC) emerges as a low capital cost and efficient complementary barrier against PhCs in the treated water. This paper reports the potential application of a newly developed waste-derived PAC for PhC removal in conventional activated sludge WWTPs, during the secondary treatment. The results obtained show that a dose of 6 mg/L of PAC will assure > 80% removal of the three PhCs tested (diclofenac, carbamazepine and sulfamethoxazole).

Keywords: Adsorption; pharmaceutical compounds; waste-derived activated carbons

Wastewater treatment plants (WWTPs) are crucial barriers against pharmaceutical compounds (PhCs) but some of these compounds are resistant to conventional treatment. Advanced treatment is an option for improving the WWTP effectiveness but in the context of financial constraints to further high technology investments in recently built plants, cost-effective solutions based on the existing infrastructures are essential. In contrast, sustainable water services demand a circular economy-driven operation of WWTPs, enabling water reuse and using renewable materials. In this context, LIFE Impetus project (2016-2019) involves a long-term field test in two Portuguese WWTPs aiming at demonstrating feasible improvement measures to enhance PhC removal in urban WWTPs with conventional activated sludge treatment (CAS), using resource efficient processes, namely by chemical enhancement with new waste-based activated carbon adsorbents. Adsorption onto activated carbon has been considered one of the best available technologies for the removal of micropollutants and waste-derived activated carbons are being produced in the latest years due to easy access of biomass and their economic and environmental friendly potential (Mestre et al., 2009). Those PACs have been mostly tested on lab scale with model waters and have yet to be applied in a real scenario context, with real waters at industrial scale.

The aim of this paper is to demonstrate the potential application of new waste-derived activated carbons for PhCs removal in CAS-WWTPs, particularly during the secondary treatment, using bench-scale tests to assist PAC adsorption demonstration at pilot and full scales. However, the PAC direct application to CAS reactor, as intended in the project, lacks in practice to fully understand its advantages (related with high contact times and PAC concentration due to sludge recirculation) and limitations (related with PAC blocking by the biomass in the mixed liquor). Therefore, the comparative results of PhC adsorption in mixed liquor and clarified water will be shown, by simulating PAC addition into CAS reactor vs. in a post-secondary step to elucidate the impact of mixed liquor on PAC adsorption efficiency.

PhC adsorption isotherms and kinetics assays were performed with a newly developed carob-based activated carbon (10 mg/L PAC in kinetic tests and 5-20 mg/L in isotherms), in mixed liquor and clarified mixed liquor. The new PAC (SCR/S900) was prepared by steam activation, according to Mestre et al. (2014), of the solid recovered from the carob pulp acid effluent which was further washed until neutral pH, and was characterised in terms of textural properties. Three target PhCs (100 μg/L) were spiked in the test waters, diclofenac/DCF (anionic relatively hydrophobic), carbamazepine/CBZ (neutral hydrophobic) and sulfamethoxazole/SMX (anionic hydrophilic), selected for their occurrence in the case study WWTPs and diversity in properties, as charge and hydrophilicity/hydrophobicity. The test waters inorganic and organic matrices were characterised. DOM fractionation in terms of hydrophobicity/hydrophilicity (Chow et al., 2004) was also carried out. PhCs were quantified by HPLC-DAD using the method detailed in Viegas et al. (2017).

The adsorption results were modelled with the Freundlich isotherm equation (Campinas et al., 2013) and the Homogeneous Surface Diffusion Model (HSDM) (Viegas et al., 2014). The results show a higher adsorption capacity for CBZ, followed by DCF and SMX. Regarding the adsorption rate, similar rates were observed for CBZ and DCF with lower rates obtained with SMX. Comparing the adsorption in clarified mixed liquor and in mixed liquor, it was observed that the particulate matter only impacts the PAC capacity towards CBZ (more hydrophobic) (19%) and DCF (relatively hydrophobic) (13%), not impacting the capacity towards SMX (hydrophilic) nor the adsorption rates.

The results obtained allowed calibrating the HSDM and predicting the removal efficiency of the PAC towards the three PhCs in pilot and full scales. The results will assist the operation of the prototypes installed at LIFE Impetus case study WWTPs for the PAC adsorption demo at pilot scale, aiming at minimising its dosing at full scale. Further adsorption assays are being carried out with different waste-based PACs (already prepared from cork processing residues and pine and pine nut wastes) to further correlate their properties and the properties of the three target PhCs and water characteristics with the fundamental parameters of their adsorption, namely with the Freundlich isotherm and the HSDM parameters, as well as to benchmark them against high-performing commercial carbons.

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