Magnetic activated carbon: an efficient and recoverable material for the removal of pharmaceuticals from water

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Background

The re-utilization of treated wastewaters is an interesting option to address water scarcity as long as environmental and public health safety are not endangered. In this sense, the effective elimination of emerging micropollutants is more than ever a hot topic. Adsorption of these micropollutants, such as pharmaceuticals, onto powdered activated carbons (PAC) is an efficient solution to be applied in wastewater treatment plants. However, the small particle size of these materials implies costly and time- and energy-consuming separation processes, hindering their large-scale applicability. To overcome this problem, imprinting magnetic properties onto PAC produced from sustainable precursors using microwave-induced pyrolysis allows to obtain highly efficient and regenerable materials that can be easily separated from treated wastewaters.

Objectives

This work aims at producing magnetic activated carbon (MAC) through the sustainable microwave pyrolysis of primary sludge from the paper mill industry (waste) and magnetization using magnetic iron oxides (i.e., magnetite and maghemite), for further application in the removal of pharmaceuticals from real wastewaters. Three pharmaceuticals were tested, namely the antiepileptic carbamazepine (CBZ), the anti-inflammatory ibuprofen (IBU) and the antibiotic sulfamethoxazole (SMX) – listed in the 2020 EU water watch-list[1] – both in ultrapure water and wastewater collected from a nearby water treatment plant.

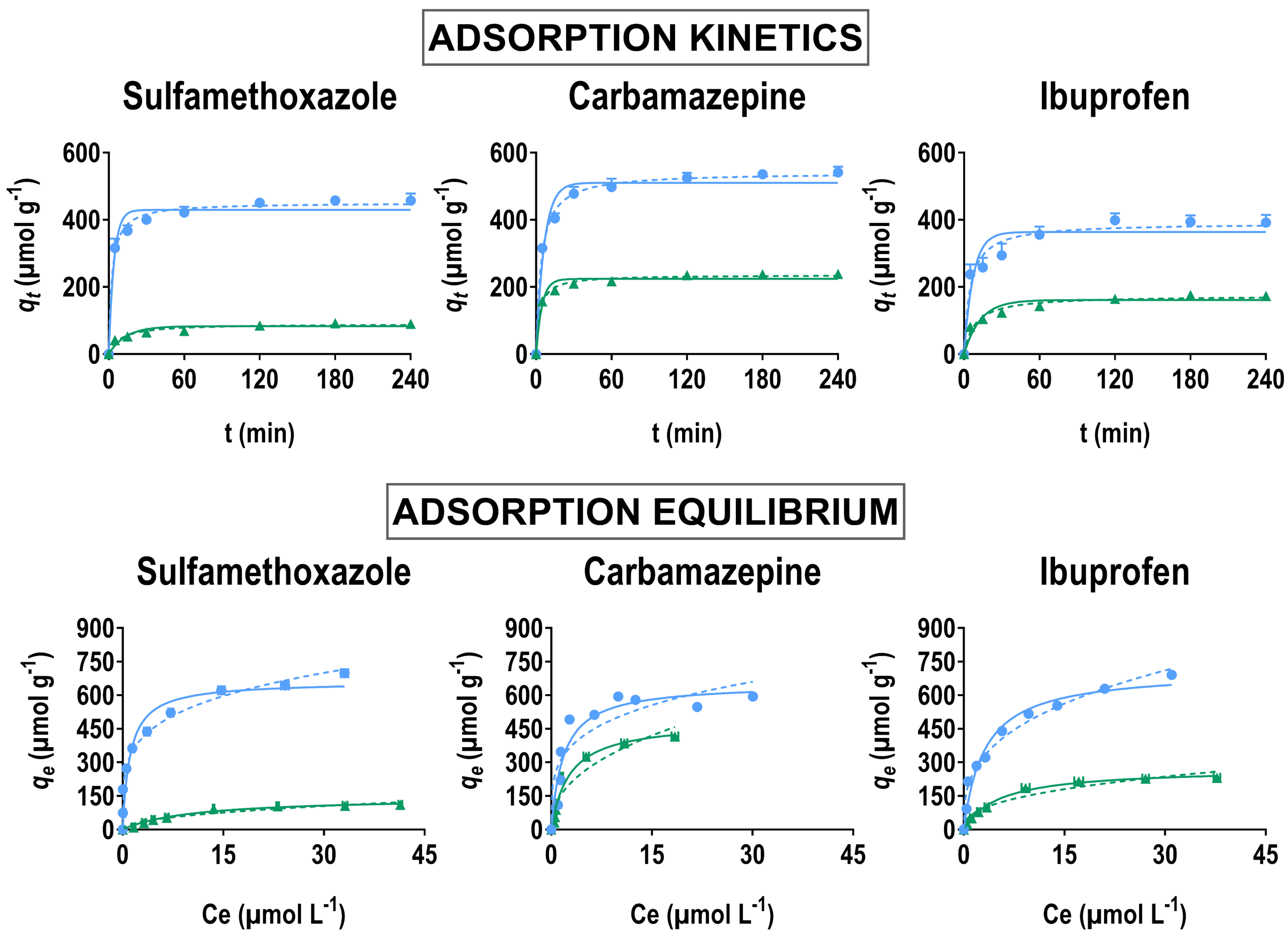

Figure 1 – MACX3 kinetic and equilibrium studies for SMX, CBZ and IBU, in **ultrapure water (blue)** and **wastewater (green)**. Kinetic adsorption models: Pseudo-first order (full line) and pseudo-second order (dashed line). Equilibrium adsorption models: Langmuir (full-line), Freundlich (dashed line). Experimental conditions: kinetics - C_{pharm} 20 µmol L^{-1}; [MACX3] 25 mg L^{-1} 25 ºC | equilibrium - C_{pharm} 2.5 - 50 µmol L^{-1}; [MACX3] 75 mg L^{-1}; 4 h, 25 ºC. q_t and q_e (µmol g^{-1}) represents adsorbed concentration of pharmaceutical at a given time (t) and at equilibrium, respectively.

Methods

PAC was produced from the carbonization of primary sludge from the paper mill industry, resulting in a material with 1082 m^2 g^{-1} of surface area. Magnetization was achieved by suspending PAC and magnetic iron oxides – previously synthesized though oxidative hydrolysis of Fe(II) salts – at controlled pH to promote surface interaction between both particles. The resulting material, MACX3 (795 m^2 g^{-1}), could be efficiently retrieved from solution using a permanent magnet.

Results

MACX3 revealed remarkable adsorptive performance in ultrapure water, and a clear decay, specially for SMX and IBU, when using wastewater as matrix, which might be attributed to several factors including wastewater pH, organic matter content and possible competing species.

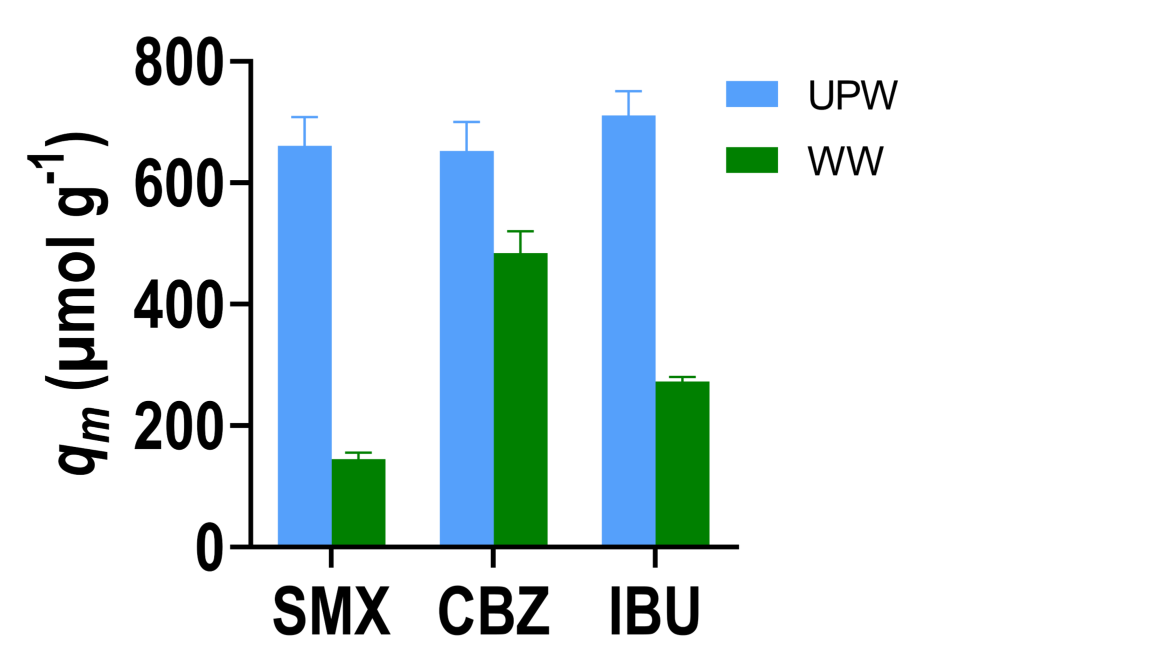

Figure 2 – MACX3 Langmuir maximum adsorption capacities (q_m µmol g^{-1}) for SMX, CBZ and IBU, in **ultrapure water (blue)** and **wastewater (green)**. UPW – ultrapure water; WW – wastewater.

Conclusions

MAC are remarkable materials that combine great adsorption performances with good magnetic properties, allowing for easy recuperation and possible reutilization of the exhausted MAC. This work proved the viability of producing MAC from residual industrial biomass. The introduction of magnetic particles in the structure of PAC inevitably decreased the surface area (26 % loss), meaning that there is a compromise to be made between magnetic properties and adsorptive performance. Nonetheless, MACX3 revealed fast adsorption kinetics (less than 1 h) and great adsorption capacity (Figure 2) in ultrapure water. Wastewater studies revealed that adsorptive performance strongly depends on pH of the effluent and the speciation of the pharmaceutical. Overall, MACX3, the result of industrial waste valorization, is potentially a powerful tool for removing emerging contaminants from water and real wastewaters.

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[1]European Commission. (2020) Official Journal of the European Union, L 257, 32–35.