Removal of analgesic pharmaceutical by adsorption onto biocarbon

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The increasing consumption of pharmaceuticals constitutes an environmental problem due to the growing presence of unaltered pharmaceuticals and their metabolites in urban and industrial wastewater (Fraiha *et al.,* 2024). The European Union has set a 2035 deadline for removing a wide spectrum of micropollutants, including pharmaceuticals that are deemed detrimental to human health. The standard processes currently used in wastewater treatment plants (WWTP) only allow to remove a portion of these pollutants (Patel *et al.,* 2019). The adsorption process has been shown to be a successful way to remove diluted pollutants from wastewater (Varsha *et al.,* 2022). However, the use of conventional adsorbents at industrial scale is limited by their high cost.

The removal of an analgesic pharmaceutical, paracetamol, from wastewater was conducted by adsorption onto a non-conventional biocarbon. The process would allow achieving zero net waste, according to the New Action Plan for the Circular Economy (European Commission, 2020), on the path towards a competitive and climate-neutral economy.

The biocarbon was prepared from renewable olive stone waste. The biomass was ground to reduce the particle size using a Fritsch Pulverisette 15 mill. Subsequently, the olive stones particles were washed with deionized water, filtered in a Buchner funnel with a filter flask connected to a vacuum pump, and then dried in an oven. Subsequently, the solids were impregnated with a H_3PO_4 solution, while stirring. Then the solids were filtered and dried. Following, the solid fractions were thermally activated and carbonized in a horizontal tubular furnace (San José *et al.,* 2026). The textural characteristics of the adsorbent, BET surface, average pore diameter and the total pore volume, the morphological structure, and the surface functional groups were determined.

The adsorption process was carried out in accordance with the ASTM D3860-98 standard (D3860-98). Solutions of paracetamol with different initial concentrations were prepared and a varying biocarbon concentration was added to the solutions. The mixtures were stirred at room temperature and liquid samples were collected at regular time intervals. The samples were then centrifuged and filtered. The adsorption process was performed in triplicate under each of the operating conditions.

The concentration of paracetamol in each sample was determined by the absorbance measured via UV-Vis spectroscopy by a SHIMADZU UV-1280 spectrophotometer based on the concentration-absorbance calibration obtained with solutions of different concentrations of analgesic. For the calibration, several solutions with known concentrations of paracetamol were prepared. A wavelength scan was conducted in the range of 190–1100 nm to determine the spectra. The wavelength corresponding to the peak of maximum absorbance for paracetamol was found at a wavelength of 243 nm.

The time evolution of the adsorption capacity and efficiency of the biocarbon during the adsorption of paracetamol was calculated using Equations (1) and (2), from the concentration of the paracetamol in the samples, until the equilibrium concentration was reached:

$$q = V(C_o - C)/S \quad (1)$$

$$\eta = (C_o - C)/C_o \; 100 \quad (2)$$

where q represents the adsorption capacity (mg g^{-1}), C_o is the initial concentration of the adsorbate (mg L^{-1}), C is the concentration of the adsorbate at time t (mg L^{-1}), V is the volume of the solution (mL), S is the mass of the adsorbent (g), and η is the adsorption efficiency.

The effect of the concentration of the adsorbent on adsorption capacity and efficiency was determined by using solutions of paracetamol and three different concentrations of adsorbent. The adsorption capacity grow with the time, first showing a noticeable trend as the adsorbent sites were available, and then exhibiting an asymptotical tendency as the adsorption sites were saturated of paracetamol. The influence of the concentration of the adsorbate was determined using solutions with three different initial concentrations of paracetamol.

In addition, the experimental data of adsorption capacity were fitted to the pseudo-first order, pseudo-second order, intra-particle diffusion, and Elovich kinetics models through a nonlinear regression analysis using the fminsearch command in MATLAB 2025b software, which minimizes the error between the experimental data and the predicted values. Furthermore, the equilibrium data for the adsorption of paracetamol onto the biocarbon were fitted to the most used isotherm models in the literature, Langmuir, Freundlich, and Sips models, which represent the nonlinear dynamic equilibrium of the adsorption‑desorption process between the adsorbate adsorbed on the adsorbent, q_e, and the concentration of the adsorbate remaining in the solution, C_e, at equilibrium using nonlinear regression analysis with the fminsearch command in MATLAB 2025b software.

In conclusion, the good performance of the activated biocarbon from the olive stones waste for removal of paracetamol from wastewater was confirmed by the high adsorption capacity and efficiency obtained in accordance with the European regulation on wastewater treatment (Directive EU 2024/3019) and national law on waste (Law 7/2022).

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