Regeneración electroquímica de carbón activado usado en plantas potabilizadoras de agua: escalado, optimización y validación de prototipos

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Objectives an Novelty

Adsorption onto activated carbons (AC) is an established technology to remove pollutants. However, one important drawback is the management of the material once its adsorption capacity is exhausted. Electrochemical regeneration is a greener alternative to the current thermal treatment method, due to the reduction of CO_2 emissions and lower energy consumption. However, this technology presents two main issues: the scaling up of the prototypes and the absence of studies with spent AC from real industries.

For this purpose, in this PhD Thesis, the electrochemical regeneration of AC used in real conditions in water treatment plants using four reactors at different scales (Figure 1), has been studied as a more sustainable method.

The specific objectives of the PhD Thesis have been: i) the scaling up of the electrochemical reactors from a TRL3 to a TRL7; ii) the optimisation of the different experimental variables to reduce the total costs as well as the environmental impact, of the process without affecting the regeneration efficiency (the studied variables are configuration of reactor, electrolyte concentration, cathodic or anodic regeneration, nature and flow rate of the electrolyte, chemical composition of anode and cathode, current density, regeneration time and the origin of the exhausted AC from different drinking water treatment plants); iii) validation of the electrochemical regeneration method of AC in the prototypes at laboratory, bench and pilot plant scales and iv) to study the adsorption capacity of an emerging pollutant such as bisphenol A on the electrochemically regenerated AC to check that the regenerated material can be reused in adsorption processes.

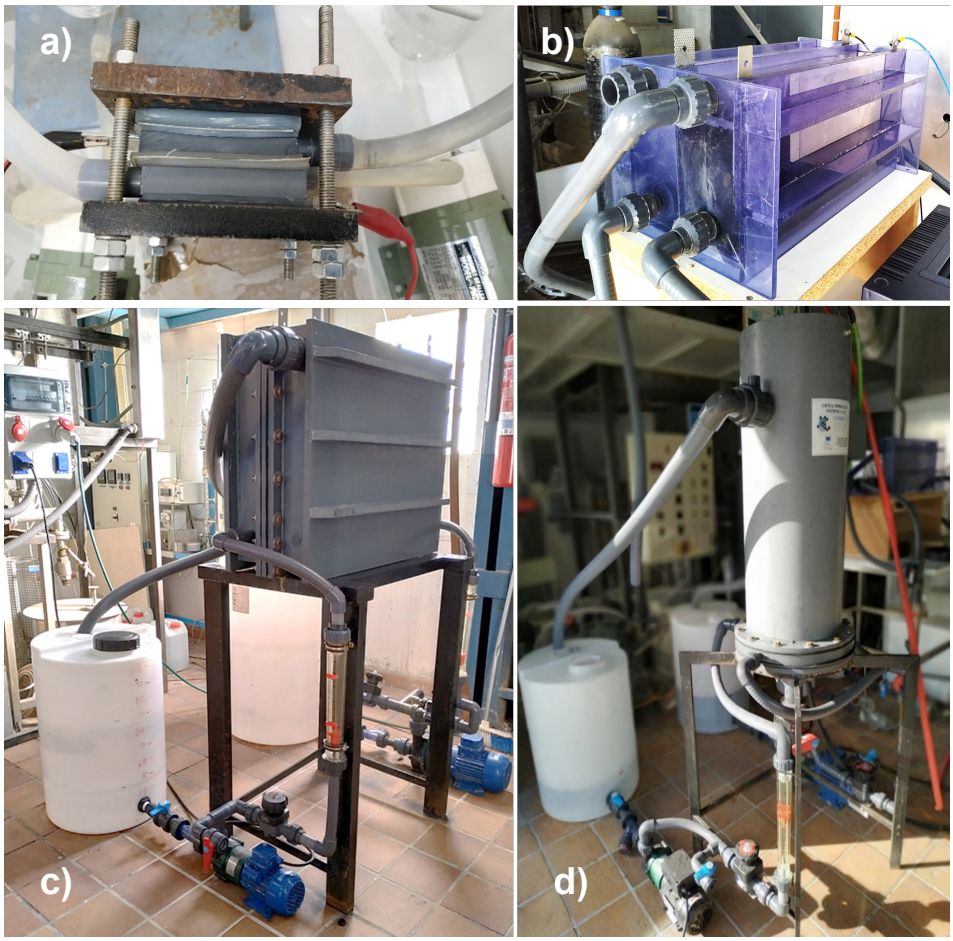

Figure 1. Electrochemical reactors used and developed in this PhD Thesis: a) filter-press cell at laboratory-scale (6 g of AC), b) parallel plate electrode reactor at bench-scale (3.5 kg of AC), c) parallel plate electrode configuration at pilot-plant-scale (15 kg of AC) and d) vertical reactor with concentric cylindrical electrodes configuration at pilot-plant-scale (10 kg of AC).

Results

The scaling-up study done from the laboratory scale reactor, showed that a direct scale-up was not feasible for building an electrochemical reactor at bench scale due to the resulting size and the required current. Therefore, modified upscaling with variation of parameters such as electrode distance, residence time and specific volume of electrolyte in the tank, resulted in easily operative and manageable reactor dimensions as well as desirable energy requirements. Thus, bench and pilot plant scale reactors were successfully built.

Regarding the AC regeneration with the laboratory scale reactor, Figure 2 shows that the pH of the process was more important than the reactor configuration. Thus, the highest recovery of the porous texture properties of AC took place using an acidic medium as electrolyte compared to a neutral or basic medium. Furthermore, although with a slight variation, a cell divided into two different compartments by a cationic membrane showed better regeneration efficiency of the carbon material compared to the configuration without separation of compartments.

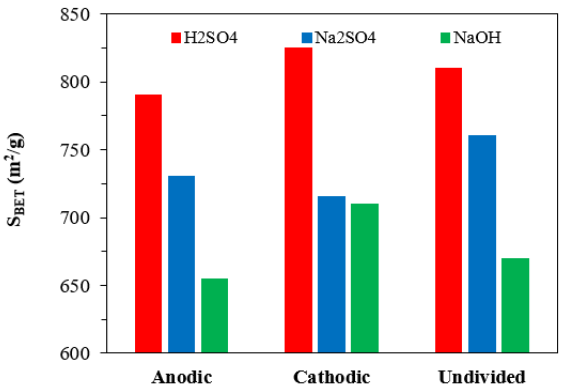

Figure 2. Effect of reactor configuration and regeneration type of AC using three different electrolytes.

The results achieved with the bench-scale reactor confirmed that using H_2SO_4 as electrolyte, a current density of 0.025 A/cm^2 and separation of compartments, the regeneration efficiency was higher than 90% after 4 h of treatment. It was also observed that the use of stainless steel as cathode, which is cheaper than the conventional Pt/Ti electrode, also produced regeneration values above 90%. In short, the results obtained on the bench-scale prototype confirmed those presented for the laboratory-scale cell, validating the scaling-up process.

Finally, the electrochemical regeneration of spent AC in a water treatment plant could be achieved using the reactors designed at pilot plant scale with parallel plane electrodes and vertical cylindrical configuration. Regarding the effect of the electrolyte concentration, it has found that the optimum concentration depends on the initial porosity of the spent AC and that the amount of inorganic matter contained in the exhausted AC has a great influence on the regeneration efficiency. Regarding the composition of the anode material, in both reactors, it was shown that dimensionally stable anodes (RuO_2/Ti and IrO_2/Ti) could be used as cheaper and efficient electrodes as an alternative to the more expensive commercial Pt/Ti in the electrochemical regeneration of AC.

Conclusions

In this PhD thesis, the electrochemical regeneration of AC at different reactor scales was reached, demonstrating that this technology can be a real alternative to the conventional thermal method used nowadays. In this work, the effect of the experimental conditions on regeneration efficiency was explored for the different prototypes designed and built. The scale-up process from laboratory (6 g) to bench scale (3.5 kg) and pilot plant (15 kg) electrochemical reactors with parallel plate electrode configuration was successfully fulfilled.

Electrochemical regeneration of spent AC used in water treatment plants, was achieved with a regeneration efficiency above 95% in the different reactors designed and built using the appropriate experimental conditions. In this sense, a reduction in energy consumption of 98% compared to the production of AC and more than 90% compared to conventional thermal regeneration technology can be achieved.

The adsorption of bisphenol A by electrochemically regenerated ACs had slightly slower kinetics than the pristine AC due to the presence of oxygen groups on the surface of the material which were mainly formed during the use of the AC in the drinking water treatment plant. However, the adsorption capacity at equilibrium conditions was similar because the regenerated AC had similar micropore volumes as the original AC.

From the validation process at laboratory scale, it was concluded that, in order to achieve a satisfactory regeneration efficiency, the surface area of the spent AC must be similar as that requested by thermal regeneration companies. The validation of the bench-scale prototype showed the feasibility of the electrochemical method for the regeneration of spent AC under real industrial conditions. Therefore, this technology can be considered as an economically and environmentally sustainable alternative to the current thermal regeneration method.

Related publications

[1] Ferrández-Gómez B, Ruiz-Rosas R, Beaumont S, Cazorla-Amorós D, Morallón E. Electrochemical regeneration of spent activated carbon from drinking water treatment plant at different scale reactors. Chemosphere 2021; 264:128399.

[2] Ferrández-Gómez B, Cazorla-Amorós D, Morallón E. Feasibility of electrochemical regeneration of activated carbon used in drinking water treatment plant. Reactor configuration design at a pilot scale. Process Safety and Environmental Protection 2021; 148:846-857.

[3] Ferrández Gómez B, Medina Ruiz FJ, Cazorla Amorós D, Morallón Núñez E. Reactor electroquímico para la regeneración electroquímica de carbón activado. Patent [P202030510] 2020; PCT international [PCT/ES2021/070334]; University of Alicante, Spain.

Full Thesis can be downloaded from www.rua.ua.es