A perspective on the preparation of value-added carbon materials from lignin

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The thermochemical conversion of lignin into different added-value carbon materials constitutes an alternative approach for valorization of this co-product that can be integrated in pulping and biorefinery processes. Such approach is based on the relatively high carbon content and the abundance of aromatic rings in the structure of raw and technical lignins. In this way, our research group have been preparing carbon molecular sieves, activated carbons, electrospun nanofibers, nanostructured and highly ordered carbons from different types of lignins during the last three decades.

Direct carbonization of lignin at temperatures between 500-800 ºC generates narrow micropororous char that can serve as carbon molecular sieves for CO_2 capture. Activated carbons with several porous structures and BET surface area up to 2400 m^2/g have been obtained via physical and chemical activation of lignosulphonates, kraft and organosolv lignins. These activated carbons have been successfully applied in adsorption and heterogeneous catalysis processes. When alkalis are found in the parent lignin, physical activation with CO_2 is promoted, and the presence of these alkalis on the surface of the resulting activated carbons can serve as promoters and even as active phase for catalysis applications. Chemical activation with H_3PO_4 produces mesoporous activated carbons with surface phosphorus groups that provides surface acidity and oxidation resistance. These features enable the use of these activated carbons in acid-catalyzed gas phase reactions under oxidizing atmosphere, showing extended operating lifetime that their P-free counterparts.

Electrospinning is a novel promising strategy for the preparation of lignin-based carbon fibers of submicron dimensions. Some of the challenges of producing carbon fibers from binder-free lignin fibers with short stabilization times can be overcome using a coaxial spinneret and the addition of phosphoric acid as cross-linking promoter. The functional properties of the obtained carbon fibers can be tuned by wise addition of doping agents and precursors into the electrospinning lignin solution. Following this approach, metal loaded carbon submicron fibers with enhanced performance as electrodes, catalysts and electrocatalysts have been obtained.

Carbons with hierarchical pore structure have been also obtained from lignin using hard templating techniques with different type of zeolites. These porous carbon materials show enhanced ion mobility in the pore network and high electrical conductivity owing to the formation of a highly ordered carbon shell from the pyrolysis of lignin. These traits enable their use as supercapacitor electrodes. Finally, the three-dimensional, cross-linked structure of lignin is a downside for achieving graphitization. Nevertheless, the conversion of lignin into highly ordered carbons is possible upon high-temperature treatment.

Also, an alternative valorization pathway includes the preparation of carbon-based catalysts for lignin catalytic conversion into platform chemicals, bioenergy and bioproducts.