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## Processing-Driven Porosity Engineering in Resorcinol–Formaldehyde-Derived Carbon Gels for High-Performance Supercapacitors

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**Key words:** carbon gels; resorcinol–formaldehyde; sol-gel polycondensation; hierarchical porosity; drying; activation; supercapacitor

Resorcinol–formaldehyde (RF)–derived carbon gels are widely recognized as promising electrode materials for electrochemical double-layer capacitors (EDLCs) due to their tunable pore structure, high carbon yield, and good mechanical, thermal, and electrical properties. This work examines how sol–gel chemistry, drying-induced capillary stresses, carbonization temperature, and activation methods collectively influence the development of hierarchical porosity, with particular focus on optimizing the micro–mesopore balance for improved charge storage.

The pore structure is largely established during the sol–gel polycondensation stage. Key synthesis parameters, including the resorcinol-to-catalyst ratio, initial pH, and solids content, control the formation of interconnected polymer networks. Adjusting these variables allows systematic tuning of particle size, pore size distribution, and network connectivity in the resulting carbon materials. Drying plays a critical role in preserving this structure. Capillary stresses generated during ambient or vacuum drying can lead to partial pore collapse and reduced accessibility. In contrast, solvent exchange and freeze-drying help alleviate these stresses, resulting in better retention of mesoporosity and improved internal surface accessibility. Consequently, the drying pathway strongly affects both pore connectivity and the efficiency of subsequent activation. Carbonization further modifies the pore structure and material properties. Higher temperatures generally enhance microporosity, electrical conductivity, and structural ordering, but may also reduce surface oxygen functionalities, affecting wettability and electrode–electrolyte interactions. The overall electrochemical performance therefore depends on a balance between conductivity, surface chemistry, and pore architecture. Additional tuning of microporosity is achieved through physical (CO<sub>2</sub>) and chemical (KOH) activation. The effectiveness of these treatments is closely linked to the initial mesoporous framework established during drying, which governs ion transport and double-layer formation.

Overall, this study highlights how coordinated control over synthesis and post-treatment steps enables the design of RF-derived carbon gels with tailored porosity for high-performance supercapacitor applications.