ABSTRACT - ORAL

Exploring Prussian blue as a safe-and-sustainable-by-design cathode material for sodium-ion batteries

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The growing demand for sustainable and safe energy storage solutions has accelerated research into sodium-ion batteries as an alternative to lithium-ion systems. Prussian blue analogues have emerged as promising cathode materials due to their low cost, environmental friendliness, biocompatibility, and favourable electrochemical properties. However, to ensure their safety, especially for vulnerable populations, it is essential to evaluate their potential toxicity alongside their electrochemical performance during the early stages of material design. Thirteen different Prussian blue particle samples were synthesized using a precipitation approach, systematically varying parameters such as flow rate, temperature, atmosphere, and the presence of ionic additives. The resulting materials were characterized using a comprehensive set of physicochemical techniques to determine particle size, crystal structure, water content, and Fe(II)/Fe(III) ratio, after which a subset was selected for parallel evaluation of electrochemical performance through rate capability testing and cellular effects, including cytotoxicity, proliferation, and differentiation capacity, in dental pulp stem cells. Our results demonstrate that developing safe and high-performing Prussian blue cathodes requires balancing two fundamental trade-offs rather than simple optimization. While smaller particles significantly improve initial capacity, excessively small sizes compromise both battery cycle stability and stem cell viability. Similarly, higher Fe(II)/Fe(III) ratios increase cytotoxicity, but they remain essential to maximize capacity and energy density in full-cell applications. Consequently, choices sub-optimal for toxicity may need to be accepted to achieve high battery performance, such as utilizing particles with a high Fe(II)/Fe(III) content. However, this risk can be partially compensated for by avoiding excessively small particle sizes. Furthermore, this highlights the value of toxicity testing, as it could enable the establishment of safe threshold levels that can guide end-of-life disposal guidelines to protect local vulnerable populations from harmful environmental exposure.