全钒液流电池流场结构优化研究摘要

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全钒液流电池凭借长循环寿命、高安全稳定性、功率与容量独立解耦的核心特性，在大规模可再生能源并网储能、电网调峰稳压、微电网稳定运行等场景中展现出显著优势，是当前电化学储能领域产业化前景广阔的技术路线之一。但在工程化应用中，常规全钒液流电池电堆流场结构仍存在突出设计短板，传统蛇形、平行式等单一流道布局易导致电解液在电极区域分布不均，局部传质阻力过大，且流道几何参数与电极多孔结构难以精准适配。这些问题会进一步加剧电池活化极化、浓差极化与欧姆极化，同时大幅增加流体泵送能耗，直接限制电池能量效率、功率密度与运行稳定性的提升，成为制约全钒液流电池规模化推广与商业化落地的关键技术瓶颈。针对上述行业共性技术难题，本文以全钒液流电池电堆流场结构为核心对象开展优化研究。基于电化学传质动力学与流体输运理论，系统分析传统流场在流体分配、传质效率、流动阻力等方面的固有缺陷，从流场拓扑形态创新设计、流道宽度/深度/间距等几何参数精细化调控、流场与电极结构耦合适配匹配三个核心层面，构建系统化、多维度的流场结构优化理论体系。研究重点聚焦于平衡电解液均匀输运与低阻流动的核心矛盾，消除电堆内部反应死区，缩短流体传输路径，提升电极内部传质动力学过程。本研究通过流场布局优化与关键参数迭代，有效强化电解液在电极孔隙内的渗透与扩散效率，弱化电池内部极化效应，降低系统泵送等辅助能耗，弥补现有流场设计在均匀性、适配性与经济性上的不足。所提出的优化思路与设计方案，可为全钒液流电池电堆结构迭代升级提供坚实理论支撑与技术参考，有助于推动电池整体性能提升与成本下降，加速其在大规模储能领域的商业化应用进程，进一步丰富与完善液流电池储能技术的结构设计理论与工程应用体系。

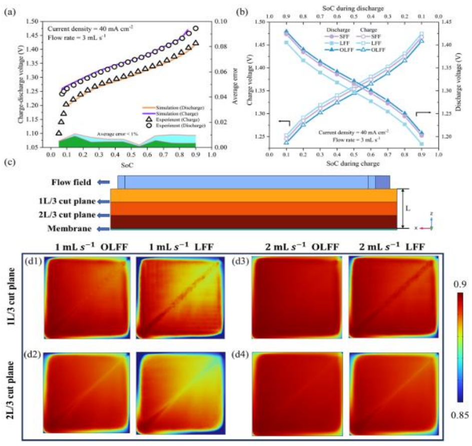

Fig. 1. (a) Comparison of the simulation data and experimental data of cell, (b) The charge-discharge voltages of three flow fields, (c) Multi-cut plane design of porous electrodes at XY plane, (d1-d4) The concentration of V2+ distributed in 1/3L and 2/3L cut plane at different flow rate (M).

关键词：全钒液流电池；流场结构优化；电堆流道；电解液传质；储能电堆

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Abstract on Optimization of Flow Field Structure for All-Vanadium Redox Flow Battery

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Abstract: All-vanadium redox flow battery (VRFB) has become a key energy storage technology in the fields of large-scale renewable energy grid-connected energy storage and power grid peak-load regulation and voltage stabilization, with prominent industrialization application potential, owing to its core advantages of long cycle life, high safety and stability, and independent decoupling of power and capacity. However, the conventional flow field structure of VRFB stacks has significant design shortcomings. Traditional single-flow channel layouts tend to cause uneven electrolyte distribution and excessive local mass transfer resistance; the mismatch between flow channel geometric parameters and electrode structure further aggravates the internal polarization effect of the battery and increases fluid pumping energy consumption, which directly restricts the improvement of battery energy efficiency and power density, becoming a critical bottleneck for the large-scale application of the technology.

Aiming at the above common technical problems in the industry, this paper focuses on the special optimization research on the flow field structure of VRFB stacks. Based on the electrochemical mass transfer mechanism and fluid transport characteristics, this paper sorts out the inherent defects of conventional flow fields such as traditional serpentine and parallel flow fields, and constructs a systematic theoretical idea for flow field structure optimization from three core dimensions: flow field topology, flow channel geometric parameters, and flow field-electrode coupling matching. The research focuses on solving the contradiction between uniform electrolyte transport and low-resistance flow, eliminating reaction dead zones inside the stack, and optimizing fluid transport paths.

Keywords: All-vanadium redox flow battery; Flow field structure optimization; Stack flow channel; Electrolyte mass transfer; Energy storage stack