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Low emissions extraction and selective recovery of vanadium

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ABSTRACT

Vanadium stands out as a critical mineral indispensable for advanced energy storage systems, particularly vanadium redox flow batteries, as well as high-strength alloys and emerging clean-energy applications such as hydrogen production catalysts. Global demand is surging due to the rapid transition toward renewable energy and electrification, particularly vanadium redox flow batteries (VRFBs), with annual VRFB capacity projected to reach ~27 GWh by 2030. Yet, supply chains face significant vulnerabilities from geopolitical constraints and limited primary mining capacity, with ~87–90% of production concentrated in China and Russia. In New Zealand, vanadium-enriched secondary resources, including industrial by-products, tailings, and waste streams, represent a strategic opportunity for domestic supply diversification. However, conventional recovery routes remain highly energy-intensive, relying on pyrometallurgical roasting followed by aggressive leaching. These processes often lead to co-precipitation of impurity metal ions (e.g., iron, aluminium, or titanium) during downstream purification, which reduces vanadium product purity, increases reagent consumption, and complicates separation economics.

A major knowledge gap persists in understanding vanadium oxide transformations and speciation control under milder, aqueous-based conditions. Specifically, the interplay between oxidation–reduction potential (ORP), pH, and moderate temperatures (40-50 °C) remains underexplored, in contrast to conventional industrial processes that rely on high-temperature roasting (typically 750–1100 °C) followed by leaching.

This study employs vanadium pentoxide as a representative model system to explore controlled reduction behaviour in aqueous media at low temperatures. Redox and pH environments were precisely manipulated using carefully selected reductants, enabling targeted manipulation of vanadium oxidation states. Reaction progression was tracked in real time through distinctive

colour transitions, complemented by comprehensive solid-phase characterisation. Precipitates were analysed using X-ray diffraction (XRD) for crystalline phase identification, scanning electron microscopy with energy-dispersive spectroscopy (SEM-EDS) for elemental composition, spatial distribution mapping, and X-ray photoelectron spectroscopy (XPS) for surface oxidation state.

The results demonstrate that reductant identity, combined with precise ORP regulation, profoundly influences the kinetics of vanadium reduction through observable colour transitions occurring over tens of minutes to a few hours, the stability of intermediate phases, and the selectivity of precipitation under mild conditions, achieving vanadium precipitation efficiencies of approximately 98%. These observations establish clear relationships between ORP, pH, and vanadium phase transformations, providing a solid mechanistic foundation for designing chemically controlled, energy-efficient vanadium recovery processes.

Ultimately, this research supports sustainable extraction from secondary resources, aligns with New Zealand's critical minerals strategy, reduces environmental footprint through lower-temperature processing, and advances circular economy principles for materials critical to global energy transition technologies.

KEY WORDS

Vanadium recovery, Critical minerals, Selective precipitation, Low-temperature processing, Sustainable extraction

BIOGRAPHY

Vidhi Phutela is a PhD student in the Department of Chemical and Process Engineering at the University of Canterbury, New Zealand. She is passionate about sustainability, innovation, and finding practical solutions to real-world challenges. Vidhi enjoys exploring new ideas, working collaboratively, and contributing to initiatives that make a positive impact on society and the environment. She is dedicated to combining creativity, curiosity, and problem-solving to help build a more sustainable and responsible future.

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