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REVIEW ARTICLE

Sustainable lithium extraction from liquid ores using membrane-based technologies: a review

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Abstract

Lithium is becoming a critical element for the economy due to the rising production of lithium-ion batteries, yet conventional extraction methods are slow, energy-intensive, and environmentally harmful. Recently, these issues have been solved partly by integrating advanced membranes in the extraction process. Here we review methods for lithium extraction with emphasis on conventional methods, membrane-based methods, multi-stage membrane-integrated systems, demonstration projects, techno-economical and life cycle assessment. Conventional methods include solar evaporation, precipitation, ion sieve adsorption, ion exchange, and electrochemical and solvent extraction. Membrane-based methods comprise reverse osmosis, nanofiltration, membrane distillation, membrane crystallization, forward osmosis and electrochemical membrane systems, ion-imprinted and ion sieve membranes, and liquid membranes. Liquid ores such as salt lakes and brines are a major source of lithium extraction and account for 2/3 of the global lithium production. Natural salt lakes and geothermal brines contain small lithium concentrations of 7.5–150 mg/L and high total dissolved solids, of 150–330 g/L. Nanofiltration allows about 85% lithium recovery with magnesium-to-lithium-ion selectivity of 0.4–0.75 and energy consumption of 35–48 kWh/kg. Electrodialysis reduces by 88% the magnesium-to-lithium ion ratio at a lower energy use of 10–38 kWh/kg of lithium. Supported liquid and ion-imprinted membranes are more energy-efficient, of 6–21 kWh/kg, but remain limited to laboratory-scale studies. We observed that the integration of membrane systems with conventional direct lithium extraction methods enhances the upstream lithium enrichment, followed by downstream recovery for more efficient overall lithium extraction.

Keywords Lithium · Critical metal extraction · Brine sources · Membrane-based sustainable mining · Clean technology

Introduction

The rising urbanization and industrial expansion drive the demand for critical metals (such as lithium), leading to accelerated and unsustainable exploitation of these metals from nature to cope with the current demand, which continuously threatens environmental quality [1, 2]. Due to significant global efforts to transition to renewable and sustainable energy sources, lithium has emerged as a critical metal in high demand as a prominent energy storage element in lithium-ion batteries [3–5]. The global energy consumption (in 2020) for the transport sector accounts for 26.18%, which can be reduced by using electric vehicles, with the highest reduction of 75% in cost for a kilometer [6]. The integration of various sources of energy, including renewable ones, can augment the system's efficiency, sustain the supply, and lower the carbon emissions in the power supply [7].

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