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SODIUM-SELECTIVE FARADAIC CAPACITIVE DEIONIZATION FOR HABITATION WATER AND NUTRIENT RECLAMATION

Abstract

Leveraging the nutrients from crewmember waste will be crucial for Environmental Control and Life Support Systems (ECLSS) to enable sustainable space travel. Conventional waste management (e.g., the urine processing assembly used on the International Space Station) recovers water, but accumulates all dissolved components (e.g., ions, organics, dissolved solids) in a brine solution for disposal; food and additional water is sent on payloads from Earth's surface. While resupply might be viable for short-term missions, establishing long-term Lunar (Artemis Base Camp) and Martian bases will require self-sufficient water recovery and food growth. In this work, we investigated selective removal of the ubiquitous ionic contaminant, sodium (Na+), to valorize mixed wastewaters containing macronutrients (K+ and NH4+) and micronutrients (Mg2+ and Ca2+) as aqueous fertilizer. We used an electrochemical faradaic capacitive deionization (CDI) cell, which is capable of reversibly inserting Na+ ions into the crystal structure of a sodium manganese oxide (NMO; Na0.44MnO2) electrode. After optimizing the current applied to the electrode, we interrogated how the operating conditions dictate sodium removal capacity and selectivity in the presence of competing cations. The presence of competing cations reduces the removal capacity and charge efficiency for sodium removal in the order of Ca2+ > Mg2+ > K+ = NH4+. We also observed competitive removal of divalent cations as a function of the cycle duration and electrode voltage. Based on these data, we conducted multi-cycle experiments to forecast the reactor size needed to achieve a given sodium removal target. Using synthetic and real mixed wastewater effluents, we show that the reactor maintains high selectivity for sodium removal over monovalent cations, which is a crucial step to achieving purified macronutrient delivery to downstream hydroponics systems. We further identified tradeoffs between sodium removal capacity and competitive cation removal by explicitly controlling the electrode voltage. In summary, this study highlights the promise of state-of-the-art faradaic CDI materials for nutrient recovery from space travel-relevant wastewaters and enumerates system improvement needs at the fundamental and unit process levels. Our operational investigation will facilitate future integration of the CDI reactor into a next-generation system architecture for sustainable wastewater recycling and resource recovery.