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High-rate electrodialysis for nutrient recovery from hydrolysed urine

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ABSTRACT

Global population growth is increasing the demand for fertilisers. However, conventional wastewater treatment typically removes or discharges essential nutrients like nitrogen (N), phosphorus (P), and potassium (K) through biological processes rather than recovering them. Human urine accounts for only 1% of domestic wastewater volume, yet it contains approximately 80% of the N, 50% of the P, and 70% of the K in wastewater. Recovering these nutrients at the source offers a practical pathway to produce liquid fertilisers. This approach can meet up to 20% of Australia's N demand and 10% of its P demand while reducing nutrient loads and greenhouse gas emissions in wastewater treatment plants (WWTPs).

Electrodialysis (ED) is an emerging technology for nutrient recovery. It can concentrate these key ions through ion exchange membranes when an electric current is applied. It can achieve a high concentration factor with relatively low energy consumption (4.9–8.5 kWh/kg NH_4-N), reducing transport and operational costs. In addition, ED minimises the transfer of micropollutants and pathogens to the final product, improving the safety of the liquid fertiliser produced.

This study investigates the feasibility of operating ED at high current densities to improve process practicality. Higher current densities accelerate ion transport and lead to faster recovery. This results in a smaller system footprint and lower capital costs. We conducted experiments using fresh, partially hydrolysed (after short-term storage), and fully hydrolysed (after long-term storage) urine at 10 and 30 mA/cm^2. Nutrient recovery performance and membrane fouling behaviour were evaluated. The results showed that 57.7± 6.5% of NH_4-N was recovered to the concentrate, at a current density of 30 mA/cm^2, with a specific energy consumption of 10.1 ± 0.6 kWh/kgN, which is lower than the average energy demand of conventional N removal processes in WWTPs (14.5 kWh/kgN).

Moreover, membrane fouling, which is often a major concern for urine treatment, was significantly reduced after urine hydrolysis, which led to the precipitation of calcium and magnesium at around pH 9. Microfiltration further helped limit fouling during ED operation. As a result, filtered hydrolysed urine could be processed for 100 hours at high current density without noticeable membrane fouling or performance decline.

Overall, this study demonstrates that high-rate ED can provide a stable and practical route for nutrient recovery from hydrolysed urine, supporting circular-economy approaches and de-centralised fertiliser production.

KEY WORDS

Wastewater treatment; Hydrolysed urine; Electrodialysis; Nutrients recovery; Liquid fertiliser

BIOGRAPHY

Yi Zhang is currently in the third year of his Ph.D. program, under the supervision of Prof. Stefano Freguia in the Department of Chemical Engineering at the University of Melbourne. His research focuses on the recovery of nutrients from source-separated urine through electrodialysis as part of the Nutrients in a Circular Economy (NiCE) Industrial Transformation Research Hub, partly funded by the Australian Research Council.

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