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Factoring in electrochemical separations

Electrification endows modern separation processes with the capability to tackle a broader array of challenges using potentially sustainable energy resources.

Separations make use of a separating agent(s) to isolate, concentrate and purify desired components from mixtures. The successful design and operation of these processes requires detailed understanding of phase equilibria, reaction kinetics, and heat, mass and momentum transfer; this underscores the critical role of separations as a cornerstone of modern-day chemical engineering.

Separations have a major footprint in many industrial processes such as petroleum refining, pharmaceutical production and water treatment, constituting a substantial fraction of the total industrial operating and capital costs (40–90%; ref. 1) and global energy consumption (10–15%; ref. 2). In recent years, however, separation science has entered a new era, which aims to replace thermal-energy-intensive processes such as distillation, due to the societal need for more sustainable, efficient and cost-effective separation solutions for a wide range of industrial applications.

Electrifying separation processes represents a viable solution for integrating renewable energy into chemical processes by offering selectivity based on electric charge. The use of electrochemical engineering principles with advanced materials and electrochemical cell designs together plays a key role in selective, efficient and high-throughput separations. Reactive carbon dioxide separations, seawater desalination, wastewater treatment, battery-material recycling and rare-earth element recovery are just a few of the many sectors where electrified separations have been successfully demonstrated[3–5]. These advancements signify an important step forward in the pursuit of more efficient chemical processes.

Showcased on the cover of this issue and reported in an Article by Cotty et al., the selective recovery of precious metals from multicomponent streams is achieved without the need for external chemical input. The authors designed an electrochemical liquid–liquid extraction process that utilizes selective single-site binding of metal ions to a redox-active molecule with ferrocene units in a continuously operating platform. This process achieved substantial up-concentration for gold and platinum group metals from several practical feedstocks including electronic waste, catalytic converter waste and mining streams, with a techno-economic analysis revealing a notable potential reduction in cost of the gold-recovery process.

As noted in a News & Views article by Boelo Schuur, traditional liquid–liquid extraction often necessitates an external driving force to increase concentration because the concentration in the back-extraction stream typically falls below that of the feed. By contrast, in the report by Cotty et al., the electrochemical redox-responsiveness of the system leads to gold concentrations post-back-extraction reaching 16 times that of the feed concentration, all without forming costly by-products and operating on potentially sustainable electricity.

At *Nature Chemical Engineering*, we are interested in all aspects of separation science, including those highlighted above based on electrochemical principles, because of the urgent need for efficient process alternatives. Solutions to such challenges will continue to require core chemical engineering principles across scales, from precisely engineered pore sizes and distributions in porous molecular sieves to larger-scale production of the designed materials to be used in industrially relevant operational modules and units.

Examples of separations-oriented Articles and commentaries can be found in this issue and our earlier issues as well as in our pre-launch collection on ‘Separations and transport processes’ covering many aspects of separations, from theoretical performance metrics to pilot-scale demonstrations. We also welcome process analyses, such as techno-economic analysis and life-cycle assessments, to propose or support optimized designs for integrated separations.

Indeed, separation processes play a critical role in process design, essential to achieving product purity and resource recovery while maintaining energy efficiency and environmental compliance across industries. Now, electrochemical engineering has the potential to become a separating factor, enabling the next generation of efficient, sustainable and economically viable industrial processes.

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