Integrated Membrane Approaches for Resource Recovery

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Membrane technologies are gaining significant attention due to their fundamental engineering principles and a broad range of applications. They offer key advantages, such as high efficiency, scalability, flexibility, and compatibility with integrated systems, making them competitive with other technologies. This work introduces the fundamentals of selected membrane technologies for water-energy-mineral resource recovery, including Membrane Distillation (MD) for water purification and brine concentration, Reverse Electrodialysis (RED) for energy generation, and Electrodialysis (ED) for mineral recovery. MD uses microporous membranes to separate volatile compounds from heated aqueous solutions (typically saline water) by utilizing the partial pressure difference created by a temperature gradient across the membrane. This temperature gradient is the critical factor determining MD performance, particularly in terms of transmembrane flux. In contrast, RED and ED employ ion-selective membranes to extract energy and minerals, respectively, from aqueous sources. Hybrid systems combining MD with RED or ED present several advantages. MD-RED systems enable simultaneous water purification and energy generation during seawater desalination, while MD-ED systems facilitate both water and mineral recovery, addressing the environmental challenges associated with conventional methods. For instance, the brine produced as retentate from MD can be repurposed for energy generation or for extracting critical raw materials like lithium through ED, while the purified water can be applied in processes such as hydrogen production via water electrolysis. However, the effectiveness of these membrane processes depends heavily on the quality and availability of suitable membrane materials. This work offers valuable insights for researchers exploring innovative water-energy-mineral solutions using membrane technologies, with a focus on sustainable and greener technological pathways.

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