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Mini Review

Mechanisms in Electro dialysis: A Comprehensive Review

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Abstract

Electrodialysis is a mature technique that has beyond the limits of brackish water desalination and continues to demonstrate its versatility for a variety of applications. Electrodialysis is now conducted in a variety of configurations under nonconventional applications and linked with other technologies in hybrid systems, parallel to the advancement of ion-exchange membranes. Recent advances in wastewater treatment and water supply are discussed throughout this chapter (Therese et al., 2019). Novel electrodialysis outcomes, including selectrodialysis, bipolar electrodialysis, reverse electrodialysis, electrodeionization, and overlimiting electrodialysis, are reviewed. The primary goals for continuous work to optimize electrodialysis systems are to provide water in remote places, save natural resources, and reduce industrial expenses (Yunusa et al., 2018).

Keywords: Selectrodialysis, Bipolar electro dialysis, Reverse electro dialysis, Electro deionization, Over limiting electro dialysis

INTRODUCTION

Electro Dialysis (ED) is a method of transporting salt ions from one solution to another using an ion exchange membrane and an applied electric potential difference. This is done in a setup known as an electro dialysis cell. This cell is made up of two electrodes and a dilute and brine compartment produced by an anion exchange membrane and a cation exchange membrane. Multiple electro dialysis cells are grouped into a configuration called as Electro Dialysis Cell (EDC) in all practical electro dialysis procedures, with alternating anion and cation exchange membranes comprising the multiple electro dialysis cells (Celestina et al., 2021). Distillation methods and other membrane-based processes, such as reverse osmosis (RO), vary from electro dialysis in that dissolved species are transported away from the feed stream rather than reverse osmosis. Because the concentration of dissolved species in the feed stream is lower than that of the fluid, electro dialysis provides the practical benefit of better feed recovery in many applications. A method called electro dialysis allows for the separation of minerals from the feed water solution under the control of an electric field gradient (Ebeye et al., 2007). It creates two distinct flows—a desalinated flow known as dilute and a concentrated flow known as concentrate (brine)—by passing dissociated ions across an ion-perm-selective membrane. It is a membrane-based method that uses an applied electric field to move ions across semi-permeable membranes (Friday et al., 2015).

Electro dialysis is an electrochemical separation technique that harnesses the mobility of ions in an electric field to selectively transport ions across ion-exchange membranes. The process holds immense promise for various industrial applications due to its ability to separate ions from solutions, especially in cases where conventional separation techniques like distillation or reverse osmosis fall short. The core components of an electro dialysis system include ion-exchange membranes, electrodes, and a power supply. Understanding the mechanisms driving ion transport and selectivity is essential for optimizing electro dialysis processes (Ogori et al., 2016).

Desalination, table salt manufacture, and wine stabilization are all examples of electro dialysis applications. The dilute feed stream (D), concentrate stream (C), and electrode stream (E) are permitted to pass through the appropriate cell compartments produced by the ion exchange membranes in an Electro Dialysis Cell (EDC). Under the influence of an electrical potential difference, negatively charged ions in the dilute stream, such as chloride, move to the positively charged anode. These ions pass through the positively charged anion exchange membrane, but the negatively charged cation exchange membrane prevents them from moving further to the anode, thus they remain in the anions-enriched C stream. Positively charged ions in the D-stream, such as sodium, move to the negatively charged cathode by passing through the negatively charged cation exchange membrane (Ashaye et al., 2006). These cations also remain in the C stream because the positively charged anion-exchange membrane prevents them from migrating to the cathode. Electric current travels between the cathode and anode as a result of anion and cation migration. Only an equal amount of anion and cation charge equivalents are transported from stream D to stream C, ensuring charge stability in each stream. The electro dialysis process produces an increase in ion concentration in the brine stream while depleting ions in the dilute solution input stream. Cation Exchange Membranes (CEM) are a type of selective barrier that separates the anode and cathode compartments. This membrane's role is to be selectively permeable to cations, especially protons, traveling from the anode to the cathode. Cation Exchange Membranes (CEM) are proton conductive polymer films that allow only protons to cross-over (cation exchange), which is the primary function of proton exchange membrane fuel cells and water electrolyzes. Cation-exchange resins are used to treat hyperkalaemia by accelerating potassium loss via the stomach, particularly when urine output is low or before dialysis, which is the most effective treatment for hyperkalaemia. The membranes are selective for cations or anion (Ajiboso et al., 2012). This implies that both positive and negative ions will flow through. Poly electrolytes with cation-selective membranes negatively charged matter that rejects negatively charged matter ions while allowing positively charged ions to pass through. The process of anion exchange membrane (AEM) Acidic anions are absorbed by a basic polymer substance. It defines the ion exchange in which one anion exchanges places with another anion (as chloride) replaces one or more anions (as sulfate). It has a strong affinity for negatively charged ions like bicarbonate and nitrates. AEC is a kind of Ion Exchange Chromatography (IEX) that is used to segregate molecules depending on their unique surface charge. Anion exchange chromatography, in particular, employs a positively charged ion exchange resin with a preference for molecules with high negative surface charges (Edem et al., 2012).

FUNDAMENTAL PRINCIPLES

Ion exchange membranes: Central to electro dialysis is ion exchange membranes, which possess charged functional groups that selectively permit the passage of either cations or anions. These membranes form distinct compartments known as electro dialysis cells. Cation exchange membranes (CEMs) facilitate the passage of cations, while anion exchange membranes (AEMs) enable the migration of anions. The combination of these membranes forms the basis for selective ion transport.

Electro migration: When an electric field is applied across the electro dialysis cells, charged ions experience electro migration, moving towards their respective electrodes. Cations migrate towards the cathode (negatively charged electrode), while anions migrate towards the anode (positively charged electrode). This phenomenon is governed by the principles of electrostatic attraction and repulsion.

Ion selectivity: Ion-selective transport is achieved through the combination of ion exchange membranes and the applied electric field. Cations or anions with higher affinity for the respective membrane can effectively pass through, while others are hindered. The selectivity of ion exchange membranes plays a crucial role in achieving high purity separations.

DRIVING FORCES AND MASS TRANSPORT

The driving forces in electro dialysis are a result of the combined effects of electro migration and electro osmosis:

Electro migration: The primary driving force, electro migration, is a consequence of the electric field applied across the electro dialysis cells. Ions experience an electric force proportional to their charge, leading to their migration towards the respective electrodes. This process is highly efficient and plays a pivotal role in achieving ion separation.

Electro osmosis: Electro osmotic flow arises due to the movement of solvent molecules in response to the electric field. This flow can influence mass transport by aiding or hindering ion migration. Controlling and minimizing electro osmotic flow is essential to enhance separation efficiency.

ADVANCEMENTS AND APPLICATIONS

Recent advancements in electro dialysis mechanisms have led to improved efficiency, reduced energy consumption, and expanded application areas:

Stack design and configuration: Novel stack designs, such as spiral-wound and plate-and-frame configurations, have optimized flow distribution and minimized concentration polarization. These advancements contribute to enhanced mass transfer and reduced energy consumption.

Ion-selective membranes: The development of advanced ion-selective membranes with improved selectivity and reduced membrane fouling has significantly increased the efficiency and lifespan of electro dialysis systems.

Pulse electro dialysis: This emerging technique involves the periodic reversal of the electric field, reducing concentration polarization and enhancing ion transport. Pulse electro dialysis shows potential for improving separation efficiency in challenging feed streams.

Wastewater treatment and resource recovery: Electro dialysis is finding applications in the treatment of industrial wastewater, enabling the recovery of valuable ions and metals. The process holds promise for sustainable resource management.

Challenges and future directions: While electro dialysis offers numerous advantages, several challenges persist:

Membrane fouling: Fouling of ion-exchange membranes remains a critical issue, leading to reduced efficiency and increased operational costs. Developing fouling-resistant membranes or effective cleaning strategies is essential.

Energy consumption: Although electro dialysis is energy-efficient compared to some separation techniques, further advancements are needed to minimize energy consumption and make the process even more sustainable.

Scale-up and commercialization: Scaling up electro dialysis processes for industrial applications requires addressing technical, economic, and logistical challenges. Research efforts should focus on translating laboratory-scale success to large-scale operations.

CONCLUSION

Electro dialysis has emerged as a promising separation technique with diverse applications, driven by the fundamental mechanisms of ion exchange, electro migration, and electro osmotic flow. Recent advancements in membrane technology, stack design, and process control have paved the way for improved separation efficiency and expanded application areas (Idowu et al., 2016). Despite challenges, electro dialysis holds tremendous potential for addressing water scarcity, resource recovery, and wastewater treatment challenges in a sustainable and efficient manner. Continued research and development efforts are essential to unlock the full potential of electro dialysis for a wide range of industrial applications.

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