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Editorial Note

Electromembrane Processes, a Toolbox for Advanced Separations

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Electromembrane processes were among the first developed membrane-based processes, but traditionally received much less attention than other methods. It was already proposed in 1890 by Maigrot and Sabates (to demineralize sugar syrup), and the configuration with permselective anion exchange and cation exchange membranes in a 3-compartment electrodialysis apparatus was an invention of Manegold and Kalauch in 1939. Electrodialysis was implemented on large scale in the USA in 1955, which is much earlier than most other membrane separation processes.

After this, the silence began. Desalination of brackish water was practiced, but for economical reasons the application was limited to a narrow range of salinities, which reduced electrodialysis to a niche process. The fundamentals and the potential of electromembrane separations remained of interest, however, and prominent membranologists like Heiner Strathmann, Victor Nikonenko and Stanislaw Koter have provided us with a strong basis to understand this fascinating approach. Eventually, the interest changed. In the early 1990's, around 25 papers on electromembrane separations were yearly published; twenty years later, this was over 250. The process has now emerged from a desalination process to a versatile tool for separations that can hardly be achieved in any other way.

Electrodialysis (reversal) uses a costly energy source: electricity. Today we are more than ever aware of the environmental cost of energy, certainly a high-quality energy source like electricity. Boundary conditions have indeed been indicated in the literature [1]. However, the benefits are huge. Charged membranes do not use filtering, but direct ion removal: keeping the concept of process intensification in mind, this is important since only those compounds that are unwanted are targeted. In principle ion exchange membranes are non-selective, but this has changed in recent years. The cost is related to the ion concentration in solution, and to the desired level of purity; this makes a good choice of the application vital.

Technology providers are traditionally in a static market of membranes and devices, with not many players. Until recently - what can be seen now is a wide range of new applications, which yields an extremely dynamic field. Table 1 shows some of the players in the ion exchange market, of which many are relatively new.

Three areas of innovation have changed - and will keep changing - electromembrane applications. The first one is related to membrane materials and types: selective membranes and bipolar membranes have allowed new applications. Membranes with selective transport are of interest for anion separation [2] and cation separation [3]. Bipolar membranes allow for separation of salts into acids and bases [4, 5]. Several challenges remain, such as Fickian back diffusion, limiting the purity of acid (and base), and membrane scaling.Work on bipolar membranes can be also found in this issue.

Table 1

Some players in the market of ion exchange membranes.

Manufacturer	Country	Commercial brand
Asahi Chemical Industry Co.	Japan	Aciplex
Asahi Glass Col. Ltd	Japan	Selemion
DuPont Co.	USA	Nafion
FuMA-Tech GmbH	Germany	Fumasep
GE Water & Process	USA	AR, CR
LanXess Sybron Chemicals	Germany	Ionac
MEGA a.s.	Czech Rep.	Ralex
PCA GmbH	Germany	PC
Tianwei Membrane Co.Ltd.	China	TWAED
Tokuyama Co-Astom	Japan	Neosepta

The second area of innovation is in separation efficiency and configurations. This should allow for efficient processes for e.g., phosphate concentration [6]. New and better membranes are essential for this feature [7]. Some of these efforts are presented in this issue.

The third area of innovation is in applications and industrial opportunities. Innovations relate to product recycling, chemical and biochemical engineering, and polymer science and technology. They are related not only to separation, but also to combined also reaction and separation, bioconversion, and energy production. Some examples are in phosphorus and heavy metals from sewage sludge [8], integrated citric acid-methane production [9] and other fermentation processes [10], separation of complex mixtures of amino acids for biorefinery applications [11], and last but not least, reverse electrodialysis [12, 13].

Enough reasons to believe that electromembrane separations are technologies to be aware of.

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