Carbon Capture and Storage With Ion-Exchange Membranes

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Abstract

Carbon dioxide (CO_2) capture and storage technologies have a role to play among the solutions to the major climate problems. Using membranes in the separation processes on which these technologies are based can be of interest, since they have a remarkable separation capacity combined with a relatively low energy demand. Ion-exchange membranes (IEMs), which allow the preferential passage of certain ions, are used for the recovery of adsorbents or absorbents used in CO_2 capture, or for the conversion of CO_2 into high-value chemical species. This chapter provides a general description of IEMs and the techniques to which they generally belong.

Key Points

- Types of IEMs including anion-exchange membranes, cation-exchange membranes, bipolar IEM, amphoteric IEMs and mosaic IEMs.
- Applications of IEMs including brackish water desalination, base and acid recovery, waste and process water treatment.
- Properties that IEMs must have and the elements on which they depend, namely high permselectivity, low electrical resistance and high mechanical, form, chemical and thermal stability which depend on the materials of which they are made and the nature and concentration of the ionic moiety inserted in them.
- Methods to synthetize these membranes which are solution casting and phase inversion.
- Applications of IEMs in CO_2 capture and storage, including reagent recovery, whether liquid reagent during capture by absorption or solid reagent by adsorption, and conversion of CO_2 into high-value molecules.
- Operation of techniques generally used when employing IEMs for CO_2 capture and storage, including bipolar membrane electrodialysis (BMED), reverse electrodialysis (RE) and fuel cells using a proton-exchange membrane.

Introduction

The major climate challenge facing humanity today is increasing the demand for new processes, whether to reduce global warming or pollution in general. Technical solutions to reduce global warming aim either to reduce or prevent greenhouse gas emissions at source, for example by controlling energy consumption or using renewable energies, or to capture and store the greenhouse gases emitted (Lecomte *et al.*, 2010). Some sectors, such as cement and glass, will always emit greenhouse gases, particularly CO_2, since the simple decarbonation of the raw material is a source of emissions (Furszyfer Del Rio *et al.*, 2022; Ostovari *et al.*, 2021; Toussaint, 2023). Even if the energy used in production is totally decarbonized, CO_2 emissions will still occur. The first category of technical solutions is therefore not sufficient on its own to achieve zero net CO_2 emissions as long as such sectors continue to operate. This is why the second category of solutions has a role to play in limiting global warming in a second phase (Anderson and Peters, 2016). Post-combustion carbon capture technologies are technologies implemented at the end of the CO_2 fixed

emission points, therefore at the end of the flue gases of CO_2 emitting industries (Chao *et al.*, 2021). The most mature carbon capture and storage (CCS) technology is based on absorption processes (Dubey and Arora, 2022; Vega *et al.*, 2020), where the CO_2 is absorbed in a liquid solvent. Moreover, technologies based on adsorption, where the CO_2 adsorbs onto a solid, are developing (Akinola *et al.*, 2022). The major disadvantage of these techniques is that the recovery of the liquid or solid solvent is very energy-intensive (Kothandaraman, 2010; Yoro *et al.*, 2021). As energy is still heavily carbon-based, research and development into other CO_2 capture technologies is expanding rapidly.

CCS techniques based on the use of membranes are becoming increasingly attractive. Indeed, membranes have remarkable separation properties combined with superior energy efficiency and a smaller environmental footprint (He *et al.*, 2022; Strathmann, 1981).

A distinction is made between gas permeation membranes, which are selective membranes that can separate CO_2 from the rest of the flue gas thanks to a difference in chemical and physical interactions between the CO_2 and the rest of the components of the flue gas with the membrane (Kothandaraman, 2010), and gas absorption membranes, which are used as a contactor between the flue gas and a liquid solvent that absorbs the CO_2, with the membranes serving to increase the contact surface between the gas and the liquid and therefore improve mass transfer (Kothandaraman, 2010).

In addition to CO_2 capture systems, the use of membranes in industrial processes has been booming in recent years, and the number of applications is constantly increasing (Strathmann, 1981). Among the different types of membrane, ion exchange membranes are membranes that promote the passage of certain ions by including anions, cations, or both, through the membrane.

Among their many areas of application, including water desalination and food processing, some are more focused on wastewater treatment or CO_2 capture and storage. In particular, they are used to recover adsorbents or absorbents used in CO_2 capture (Valluri and Kawatra, 2021), or to convert CO_2 into high-value chemical species (Tian *et al.*, 2021). They are generally parts of processes involving electrodialysis, reverse electrodialysis or fuel cells. Some key applications of IEMs are listed in **Table 1**.

There are different types of IEMs, namely monopolar IEMs, containing only cations or anions, and therefore being permeable to anions or cations respectively (Luo *et al.*, 2018); bipolar IEMs, which consist of a cation- and anion-exchange membrane (CEM and AEM), two monopolar IEMs, laminated together (Grot, 2011; Pärnamäe *et al.*, 2021); and amphoteric and mosaic IEMs which contain both anions and cations, and therefore being permeable to both cations and anions (Pismenskaya and Nikonenko, 2021). All these membranes must present certain properties in order to ensure their long-term durability and the proper functioning of the techniques using them. Their properties are mainly governed by the membrane material and the type and concentration of the fixed ionic moiety (Grot, 2011). These membranes are generally manufactured by solution casting followed by phase inversion (Jiang *et al.*, 2021) and the insertion of ionic moieties by chloromethylation followed by quaternization and by sulfonation for AEM and CEM respectively.

The aim of this chapter is to provide a wide range of information on IEMs and to highlight their particular interest in the fields of CO_2 capture and storage.

Background and Operating Principles of IEMs

Types of IEMs

A selective membrane is a thin film acting as a selective barrier to separate two phases (liquid-liquid, gas-gas or liquid-gas). Membranes can be solid, liquid or a gel, and can be made of various materials, such as carbons, alumina or zeolites in the case of inorganic membranes, and as natural or synthetic polymers for organic membranes (Saleh and Gupta, 2016). The separation efficiency of a membrane is defined by its selectivity, which describes its ability to let specific substances through while retaining others (Saleh and Gupta, 2016).

The classic and most widely commercialized IEMs are monopolar IEMs (Asante-Sackey *et al.*, 2021), which include CEM and AEM. The former must allow positively charged ionic species, cations, to pass through and retain negatively charged ionic species, anions. Conversely, AEM must allow anionic species to pass through while retaining cations. To achieve these properties, the

Table 1 Applications of ion exchange membranes.

Applications	*References*
Brackish water desalination	(Strathmann, 2004)
Base recovery	(Ran *et al.*, 2017)
Acid recovery	(Ran *et al.*, 2017)
Production of acid and base	(Ran *et al.*, 2017)
Boiler feed water production	(Strathmann, 2004)
Ultra pure water production	(Strathmann, 2004)
Waste and process water treatment	(Strathmann, 2004)
Demineralization of food products	(Strathmann, 2004)

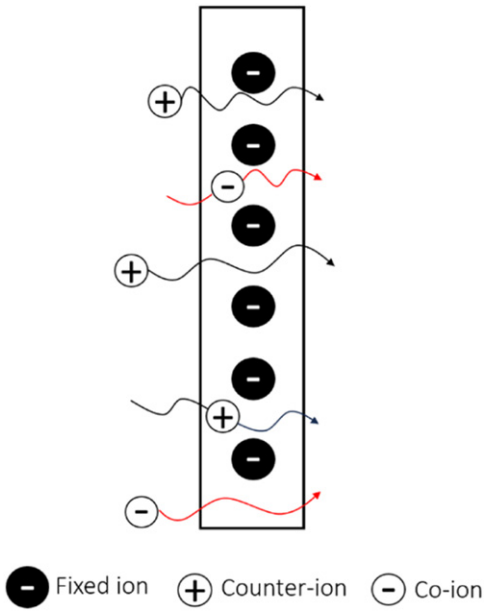


Fig. 1 Illustration of the structure of a CEM.

membranes contain fixed anions or cations, respectively, to repel ionic species of the same charge and attract those of opposite charge (Grot, 2011). **Fig. 1** shows the structure of a CEM fixed anions, called the fixed-ions, cations crossing the membrane, called counter-ions, and the few anions able to cross the membrane despite the presence of fixed negative charges, called co-ions. An ideal CEM is permeable only to cations, and therefore allows no anions to pass through (Grot, 2011). For an AEM, **Fig. 1** is valid with the positive and negative charges reversed.

In addition to monopolar IEMs, there are more complex types of IEM, based on the same principles. There are bipolar IEMs which consist of a CEM and an AEM laminated together (Grot, 2011), as shown in **Fig. 2(a)**. These membranes are attracting increasing research interest because of their energy efficiency and low environmental impact (Jiang *et al.*, 2018). They have applications in chemical production and separation, and can be used for antifouling, water dissociation or separation of mono and divalent ions (Peterson, 2008).

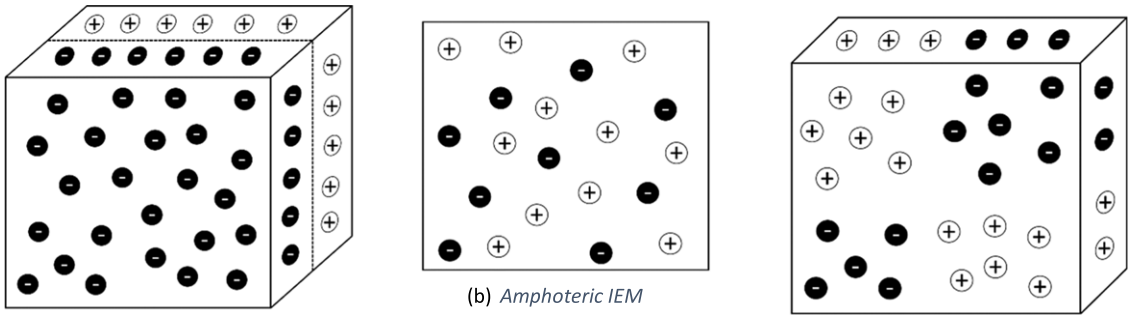
Furthermore, there are amphoteric and mosaic IEMs which both contain fixed cations and anions, and therefore have the advantage of being able to pass both ionic species. The difference between these membranes lies in the arrangement of the ions in the polymer matrix. The ions in amphoteric IEMs are randomly distributed in the matrix, as shown in **Fig. 2**(b), whereas in mosaic IEMs, the anion and cation exchange elements are arranged parallel to each other, see **Fig. 2**(c). In the latter, anions and cations can flow through individual channels, but unfortunately these membranes are complex to synthesize and unsuitable yet for industrial production (Peterson, 2008). However, they are of research interest due to their unique properties, such as negative salt rejection and osmotic pressure, which make them suitable for different separation approaches for waste streams or other high salt solutions (Peterson, 2008). Amphoteric IEMs, meanwhile, are attracting research attention for wastewater treatment and seawater desalination (Ma *et al.*, 2019) and have the advantage of being an antifouling material that prevents the adsorption of organic molecules and biological macromolecules on the surface (Othman *et al.*, 2022).

Properties of IEMs

IEMs must possess certain properties to ensure quality separation. They must have high permselectivity, meaning that their permeability to counter-ions must be high, while that to co-ions must be low. Moreover, low electrical resistance is desired, so that when an electrical potential gradient is applied to the membrane, its permeability to counter-ions is as high as possible. To ensure a long useful life under operating conditions, their mechanical, form, chemical and thermal stability must be high. Form stability means exhibiting a low degree of swelling or shrinkage when changing from dilute to concentrated ionic solutions while chemical stability means that membranes must be stable over the whole pH range and in the presence of oxidizing agents (Grot, 2011).

These properties depend on the membrane material and the type and concentration of the fixed ionic moiety, the former largely determining the mechanical, chemical, and thermal stability of the membrane and the latter its permselectivity and electrical resistance (Grot, 2011).

The material constituting the IEM is generally an organic polymer, for instance polypropylene or polyethylene. Furthermore, the membrane can be formed by an organic-inorganic composite material, known as hybrid ion exchange membranes (Peterson, 2008). The presence of these two components makes it possible to combine their properties, such as the structural flexibility of the organic component and the mechanical rigidity and thermal stability of the inorganic one (Peterson, 2008).



(a) *Bipolar IEM* (b) *Amphoteric IEM* (c) *Mosaic IEM*

Fig. 2 Categorized IEMs.

Anions used as fixed charges in CEMs include sulfonic group (SO_3^-), carboxylic acid base (COO^-) and phosphate group (PO_3^{2-}), while cations used in AEMs include amino groups (NH_3^+, RNH_2^+, R_2NH^+) or vinyl pyridine rings (Ma *et al.*, 2019).

Moreover, the concentration of the fixed ionic moiety in polymer membranes has a significant effect on their mechanical properties through their degree of swelling (Grot, 2011). Indeed, swelling, which results from the slow diffusion of solvents into polymer chains (Yaqian, 2022), is all the greater the higher the concentration of ionic species in a hydrophobic polymer matrix (Grot, 2011), and this swelling can impact in-situ mechanical stresses and the mechanical durability of the membrane (Sadeghi Alavijeh *et al.*, 2019). To limit swelling, polymer membranes are often cross-linked (Grot, 2011), since the higher the degree of cross-linking, the lower the degree of swelling (Kim *et al.*, 1993). Increasing the degree of crosslinking increases the mechanical strength of the membrane. Unfortunately, it simultaneously increases its electrical resistance, which is undesirable. This is not the only case in which the variation of a parameter has a positive impact on one property and a negative impact on another (Grot, 2011). Another example just discussed is the increase in concentration of fixed ionic charges which decreases the electrical resistance while increasing the degree of swelling and therefore reducing the mechanical stability (Grot, 2011).

Furthermore, the properties of the IEMs described above depend on how the charge group and matrix phase are interconnected (Asante-Sackey *et al.*, 2021). Homogeneous and heterogeneous IEMs are distinguished from each other. The ion exchange material is chemically bonded to a polymer backbone for the former and it is mixed with the polymer matrix without chemical bonding to this matrix phase for the latter (Asante-Sackey *et al.*, 2021). Homogeneous IEMs offer slightly superior electrochemical properties, with higher permselectivity for counterions and lower electrical resistance (Ma *et al.*, 2019), as well as a more balanced distribution of functional sites (Asante-Sackey *et al.*, 2021). However, they are more expensive and complex to produce than heterogeneous IEMs (Asante-Sackey *et al.*, 2021) and have poorer mechanical strength (Ma *et al.*, 2019).

Synthesis of IEMs

Most commonly, membranes are manufactured by solution casting followed by phase inversion (Fernandes *et al.*, 2001; Jiang *et al.*, 2021). Phase inversion is a process during which a thermodynamically stable polymer solution is transformed from a liquid into a solid state in a controlled manner (Hołda and Vankelecom, 2015). First, there is a liquid-liquid demixing between a polymer-rich phase and a polymer-poor phase. The former then solidify and form the membrane (Hołda and Vankelecom, 2015).

There are three types of phase inversion, namely thermally induced phase separation (TIPS), vapor-induced phase separation (VIPS), and non-solvent induced phase separation (NIPS) (Jiang *et al.*, 2021). In the case of IEMs, it is the latter that is generally adopted, which involves preparing a polymer solution that is cast into a thin wet film and then immersed in a solvent-free bath to induce phase separation. Pore size can be effectively controlled with NIPS but the phase separation process is more difficult to control (Jiang *et al.*, 2021). Another way of producing IEMs is by solvent evaporation after solution casting, which results in a dense, nanoporous structure. In this case, volatile solvents are generally used and evaporation can be accelerated by applying heat (Jiang *et al.*, 2021).

The introduction of functional sulfonic groups into the polymer matrix of CEMs typically involves sulfonation, with concentrated sulfuric acid or chlorosulphonic acid being used as sulphonating agents. For AEMs, two successive steps are typically required, namely chloromethylation followed by quaternization in order to introduce quaternary ammonium groups (Jiang *et al.*, 2021).

Ion Exchange Membranes for CO_2 Capture and Storage

Table 2 shows various applications of IEMs in the field of CO_2 capture and storage (Wang *et al.*, 2022). IEMs can be used to recover CO_2 and the materials that have adsorbed or absorbed it during capture, as well as to convert the captured CO_2 into more valuable chemical compounds, such as syngas (CO, H_2) or methionine. The same techniques are often used for different applications, such as electrodialysis, bipolar membrane electrodialysis (BMED), reverse electrodialysis (RE) and the use of fuel cells. These are developed in section "Main Techniques Using IEMs".

Table 2 Applications of IEMs in the domain of CO_2 capture and storage.

Applications	*Techniques*	*Performances*	*Authors and references*
Reagent regeneration after CO_2 capture by absorption.	Electrodialysis with bipolar membrane separation.	Lower energy consumption compared to thermal regeneration commonly used (1.18 vs 3–4MJ/kg- CO_2).	(Valluri and Kawatra, 2021)
Conversion of CO_2 captured into formate by extracting the energy from salinity gradient and wastewater.	Microbial RE CO_2 reduction cell including RE containing AEM and CEM.	Maximum formate concentration of 185.4 $\pm$ 6.1 mg L $-$ 1 and faradaic efficiency of 88.9 $\pm$ 3.2% were yielded with anodic COD removal up to 87.0 $\pm$ 4.3%.	(Tian *et al.*, 2021)
Resin bed regeneration after CO_2 capture by adsorption.	pH swing regeneration using an electrochemical cell including one membrane electrode assembly, which contains proton-exchange membranes (PEM), and one CEM.	Highest CO_2 capture capacity measured: 1.76 mmol · g–1 dry resins. No apparent resin degradation after 150 cycles of adsorption–desorption.	(Shu *et al.*, 2022)
Syngas synthesis from carbonate electrolyte obtained from CO_2 capture.	Direct electrochemical reduction of carbonate using a bipolar membrane.	Pure syngas at a 3:1 H_2 : CO ratio generated at a current density of 150 mA/cm2 and an energy efficiency of 35%.	(Li *et al.*, 2019)
CO_2 capture (by absorption) and extraction of methionine.	CO_2 captured via absorption with methionine salt. Conversion of the mixture into methionine and CO_2 through BMED.	High-purity methionine obtained. Successful recovery of CO_2. Methionine extraction ratio: 99.57%. Energy consumption: 7.0 kWh/kg CO_2.	(Jiang *et al.*, 2021)
The recovery of aniline from salty aniline wastewater and CO_2 from flue gas after a pre-desalination, CO_2 capture and aniline removal three steps process.	BMED to remove aniline from the feed compartment and then collect in base compartment and simultaneously recover CO_2 in acid compartment.	Due to the higher CO_2 partial pressure, operation with 100% and 50% CO_2 in the fuel gas stabilized at a lower pH than in the 30% case.	(Wang *et al.*, 2016)
Electrocatalytic conversion of CO_2 into fuels and chemicals at near- ambient temperatures and pressures.	Zero-gap electrochemical CO_2 reduction reaction (CO2RR) reactors containing an AEM.	Zero-gap CO2RR reactors containing AEMs have demonstrated stable, high efficiencies (that is, selectivities $>$90% and cell voltages 100 h) at high current densities ($>$200mAcm–2).	(Salvatore *et al.*, 2021)
Capture of ambient air CO_2 from municipal wastewater mineralization.	CO_2 adsorption with an IEM, releasing CO_2 when it is wet.	The adsorption capacity of CO_2 (gas) after five cycles of adsorption and regeneration of the membranes suffered a loss of approximately 4%.	(Monteagudo *et al.*, 2021)
Humidified CO_2 conversion into H_2 and CO.	Alkaline AEM- and PEM-based fuel cell reactors.	Best results with Cu/CNTs cathode catalysts: onset potential of $-$ 1.0 V for CO_2 reduction reaction and CO production rate of 8.88 μmol h $-$ 1 cm $-$ 2 at $-$ 3.0 V.	(Wang *et al.*, 2018)
Production and separation of acetic acid from CO_2.	AEM microbial electrosynthesis cell.	Maximum amount of acetate product produced of 0.72 mmol after 19 operational days.	(Matemadombo *et al.*, 2017)

Main Techniques Using IEMs

In this section, the operation of the techniques often used when employing IEMs for CO_2 capture and conversion is developed. Indeed, the different techniques from **Table 2** in section "Ion Exchange Membranes for CO_2 Capture and Storage" are often the same, namely BMED used for the regeneration of the reagent used for CO_2 capture (Valluri and Kawatra, 2021), for the conversion of captured CO_2 into methionine (Jiang *et al.*, 2017) and for a three-stage CO_2 capture and aniline removal process (Wang *et al.*, 2016), RE when converting captured CO_2 into formate (Tian *et al.*, 2021) and the use of cells to regenerate a resin bed after CO_2 capture by adsorption (Shu *et al.*, 2022) and to convert captured CO_2 into H_2 and CO (Wang *et al.*, 2018) and acetic acid (Matemadombo *et al.*, 2017). As BMED and RE are techniques close to electrodialysis, the latter is explained in this section. There are other techniques based on the use of IEMs, such as continuous electrodeionization, diffusion dialysis or Donnan electrolysis, but less relevant in the field of CO_2 capture and storage.

Electrodialysis

The objective of electrodialysis is to create ionically concentrated and depleted streams, called the concentrate and dilute streams, respectively, from an initial ionic solution such as an aqueous salt solution (Gurreri *et al.*, 2020). It plays an important role in

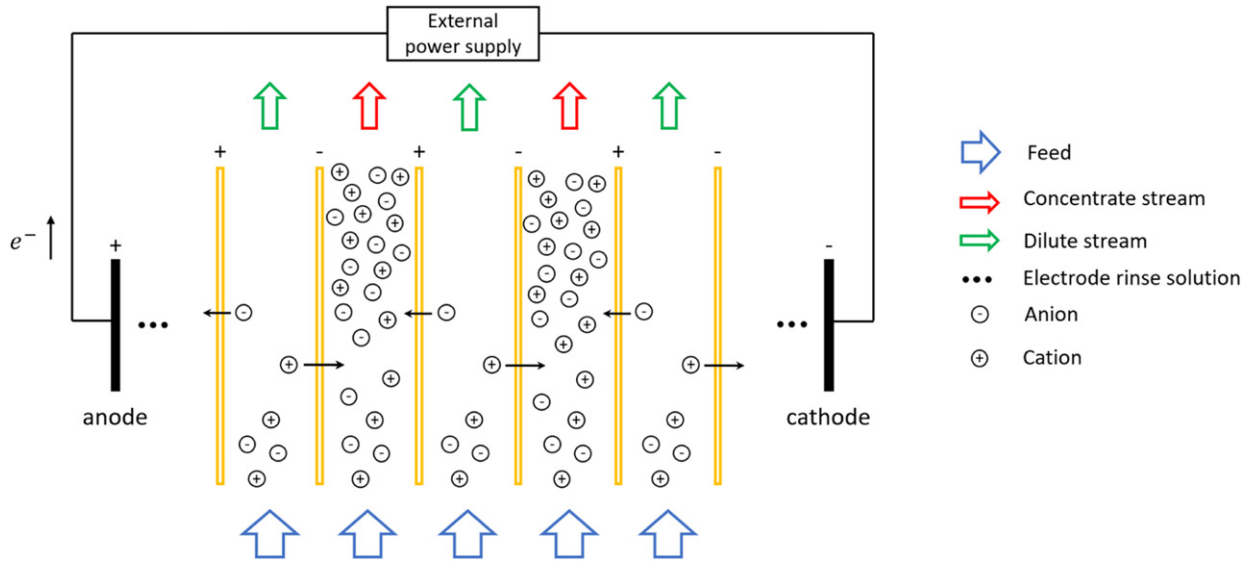


Fig. 3 Electrodialysis cell representation.

large-scale mass separation in industry, being in direct competition with distillation and reverse osmosis (Chen *et al.*, 2008; Generous *et al.*, 2021; Strathmann, 2004), which are other widely used separation processes. Currently, its main application is the desalination of saline solutions, whose products of interest may be ionically depleted potable water or concentrated brines and salt-depleted water for industrial use (Strathmann, 2004).

An electrodialysis cell, shown in **Fig. 3**, consists of an anode and a cathode, powered by an electric current, between which CEM and AEM are alternated. Thanks to the electrical potential difference applied to them, the anode and cathode provide the driving force enabling anions to migrate to the anode and cations to the cathode, and thus leave the dilute streams, and the alternation of AEMs and CEMs blocks the cations and anions in the concentrate streams. The volume between two membranes forms an individual cell. The individual cells thus contain alternating dilute and concentrate streams, with ions leaving the former to concentrate in the latter. There is thus a repeating unit comprising two contiguous dilute and concentrate streams and two contiguous AEM and CEM. A limited number of AEMs are shown in this figure, whereas in practice, an electrodialysis unit may comprise hundreds (Strathmann, 2004).

Bipolar Membrane Electrodialysis (BMED)

BMED is an electrodialysis process combined with bipolar IEMs. It is used to produce the corresponding acids and bases from the supplied salts (Bazinet *et al.*, 1998). The bipolar membrane plays an essential role in this process, as it specifically catalyzes the dissociation of the water contained in the salt solution to form free protons (H^+) and hydroxide anions (OH^-) (Valluri and Kawatra, 2021), chemical species that form acids and bases.

A BMED cell, shown in **Fig. 4**, has the same composition as an electrolysis cell, described in section "Electrodialysis", with the difference that bipolar membranes are alternated with CEMs and AEMs. The H^+ and OH^- ions formed at the bipolar membranes, moving towards the cathode and anode respectively due to the electrical potential difference, are blocked by the AEMs and CEMs respectively, as are the ions from the saline solution. The latter are subject to the same principle as in conventional electrodialysis, but now react with the H^+ and OH^- ions to form the corresponding acids and bases (Strathmann, 2004), following these reactions :

$$H^+ + X^- \rightarrow HX \tag{1}$$

$$M^+ + OH^- \rightarrow MOH \tag{2}$$

with X^- and M^+ the anion and the cation of the saline solution respectively.

The IEMs used, which must fulfill certain characteristics as explained in section "Properties of IEMs", must therefore be particularly stable in highly concentrated acid and alkaline solutions (Strathmann, 2004).

The repeating cell unit now consists of three streams: those containing the acid, the base and the dilute feed solution.

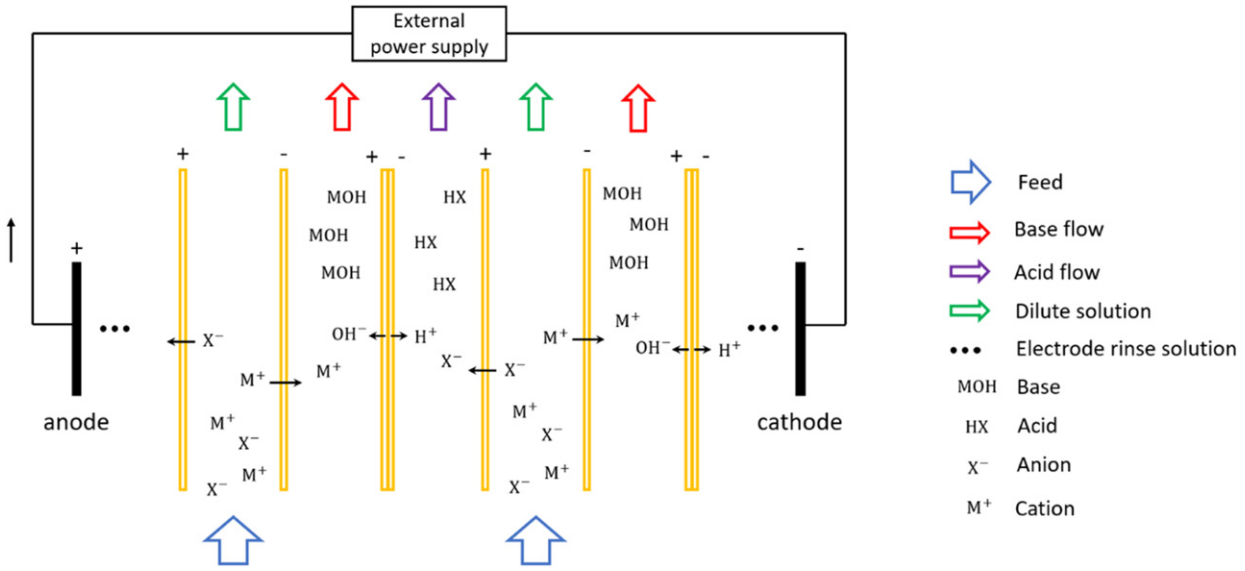


Fig. 4 BMED representation.

Reverse Electrodialysis (RE)

RE is a process which is the opposite of electrodialysis, explained in section "Electrodialysis". Indeed, whereas electrodialysis consists in separating a saline solution into a concentrated and diluted stream using an electric current, the RE consists in creating an electric current using diluted and concentrated saline solutions (Mei and Tang, 2018). These solutions are generally river water and seawater respectively. However, as river water is often dedicated to other uses, such as agricultural irrigation, it can be replaced by municipal wastewater, if the wastewater treatment plant is sufficiently close to the sea (Mehdizadeh *et al.*, 2020). This process therefore produces energy which is envisaged as a power source for other processes such as reverse osmosis, electrodialysis or membrane distillation (Othman *et al.*, 2022).

The RE system, shown in **Fig. 5**, consists of alternating AEM and CEM and of an anode and a cathode connected to an external load. High- and low-salinity solutions alternate in the system. Ions from the concentrated stream are pushed through the IEMs to the diluted stream, according to the osmosis principle. Since AEMs allow only anions to pass through, and CEMs only cations, anions move towards the anode and cations towards the cathode. Ions with opposite charges therefore move in opposite directions, creating an electric current, a voltage difference, known as the Donnan potential, at the electrodes through redox reactions. This voltage can be amplified by increasing the number of cells, namely the number of units comprising an AEM and a CEM (Othman *et al.*, 2022).

Fuel Cells Using a PEM

A fuel cell is a device for generating electricity from chemical potential energy released during a spontaneous reaction. It consists of an anode and a cathode between which is an electrolyte substance (Lucia, 2014a; Sazali *et al.*, 2020). It features two input streams, including the fuel, as well as two output streams, including the unreacted fuel. There are various types of fuel cell, classified according to the fuel and electrolyte substance used. In the framework of IEMs, the electrolyte that can be used is a PEM, which is an IEM that allows only protons H^+ to pass through (Lucia, 2014b). In that case, the fuel considered is hydrogen (H_2).

The second input and output streams are respectively oxygen (O_2), which often comes from the atmospheric air, and water (H_2O), as shown in **Fig. 6**.

The overall spontaneous reaction is:

$$2H_2 + O_2 \rightarrow 2H_2O \tag{3}$$

In practice, it takes place in two steps at two different positions in the fuel cell (Fărcaş and Dobra, 2014).

The first reaction, namely the dissociation of hydrogen into proton H^+, takes place at the anode:

$$2H_2 \rightarrow 4H^+ + 4e^- \tag{4}$$

The kinetics of this reaction are enhanced by the presence of the catalyst layer on the anode, usually platinum (Lucia, 2014b). The protons generated by the reaction pass through the PEM electrolyte and the electrons reach the cathode via the electrical circuit, generating an electric current in the external load as well as some waste heat (Fărcaş and Dobra, 2014).

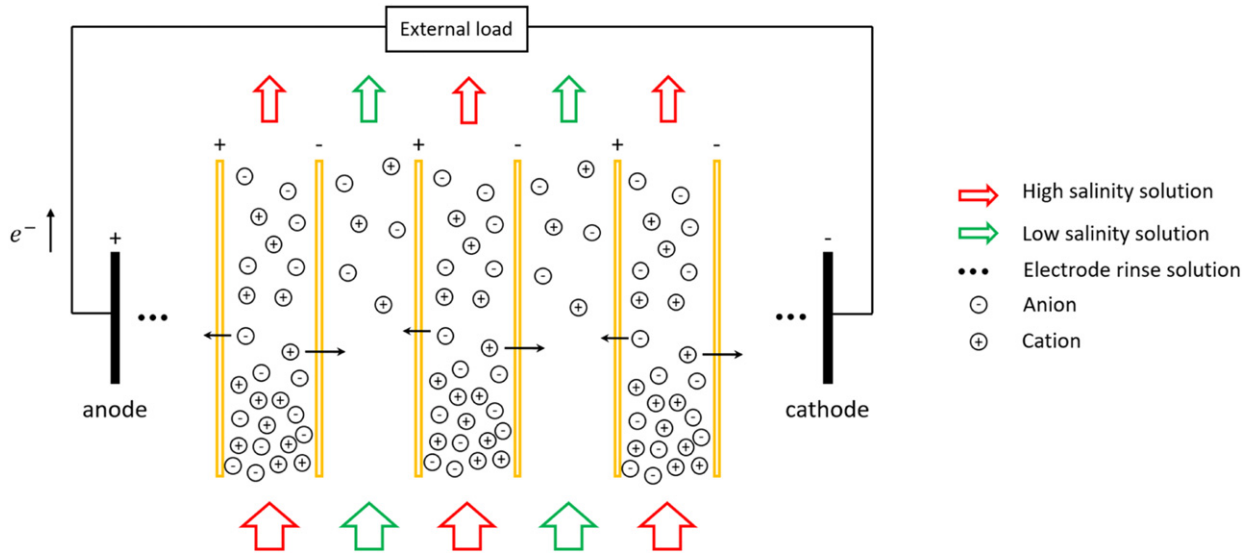


Fig. 5 RE representation.

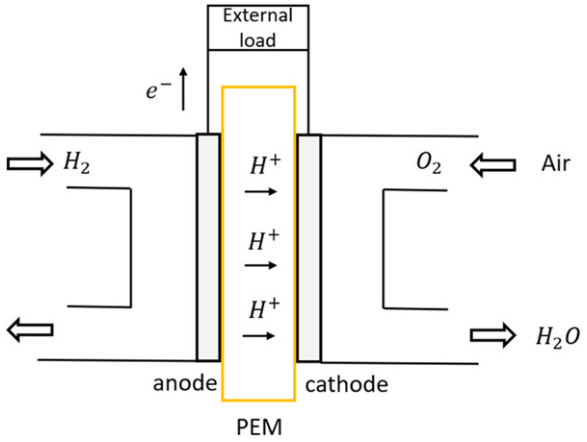


Fig. 6 Fuel cell representation.

The second reaction takes place at the cathode:

$$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O \tag{5}$$

As for the reaction at the anode, a platinum catalyst is used to enhance the kinetics of this reaction (Lucia, 2014b). As long as the fuel (H_2) is fed, electricity is produced.

Conclusions

This chapter has provided a wide range of information about IEMs, namely their various fields of application, the different types of IEMs, the properties that they must have and the elements on which these properties depend as well as the methods to synthetize these membranes. However, it has focused on the use of IEMs in the capture and storage of CO_2, notably for reagent recovery, whether liquid reagent during capture by absorption or solid reagent by adsorption, or for the conversion of CO_2 into high-value molecules. The techniques behind these capture or storage processes based on the use of IEMs are often similar : (i) electrodialysis consists of separating a saline solution into ionically concentrated and depleted solutions using an electric current between two electrodes, (ii) BMED is very similar to the first but its concentrated streams contain the bases and acids associated with the cations and anions contained in the initial saline solution, (iii) RE, unlike electrodialysis, creates an electric current between two electrodes via the formation of a saline solution from ionically concentrated and depleted solutions, and (iv) the use of fuel cells which can contain a PEM as electrolyte for the generation of electricity from hydrogen and oxygen.

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