

# A Simple One-Dimensional Model for the Analysis of a Bipolar Membrane Used in Electrodialysis Desalination

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## 1. Introduction. Model description

Industrial effluents based on salt solutions of high concentration (mainly composed of NaCl and KCl), generated after processing or by neutralizing acid/base streams, are challenging to treat by conventional desalination methods, like reverse osmosis. Recently, an electrodialysis method based on bipolar membranes (BPM) was designed to dissociate an aqueous saline flux into its corresponding base and acid without adding chemicals [1,2], a process considered sustainable and environmentally friendly [3].

An improvement of the bipolar membrane efficiency is directly correlated with a better understanding of the ion transport processes coupled with chemical reactions via different theoretical approaches and numerical models.

A bipolar ion-exchange membrane is a polymeric membrane formed by three layers: a strong base anion-exchange layer (AEL), a strong acid cation exchange layer (CEL) and a junction layer, as we can see in fig. 1. This interface layer (IL) is usually under the form of a catalyst layer of several nanometers in thickness, promoting water dissociation. The interface layer can be modelled most simply as an infinitely thin plane (abrupt junction). This layer plays a crucial role in the functionality of BPMs, being the place where water is electro-dissociated into protons and hydroxide ions.

This model adopted a three-layer "electrolyte-bipolar membrane-electrolyte" configuration, as we can see in fig. 1. This model describes the one-dimensional, non-stationary transport of salt ions ( $K^+$  and  $Cl^-$ ) from the CEM and AEM to the electrolyte layers. The water dissociation into ions ( $H^+$  and  $OH^-$ ) and their subsequent transport were also considered here.

Under the Wien effect, water behaves like a weak electrolyte inside the depletion layer. The dissociation into  $H^+$  and  $OH^-$  ions is developed mainly between those  $+\lambda$ ,  $-\lambda$  boundaries (see fig. 1). An electric field is applied between the anode and cathode of the three-layer system.

The transport of  $K^+$  and  $Cl^-$  ions will generate a current flux carried by  $H^+$  and  $OH^-$  ions to pass both layers of the BPM to the electrolyte layers. Here, the salt ions and dissociation products will be attracted towards the electrode of opposite charge.

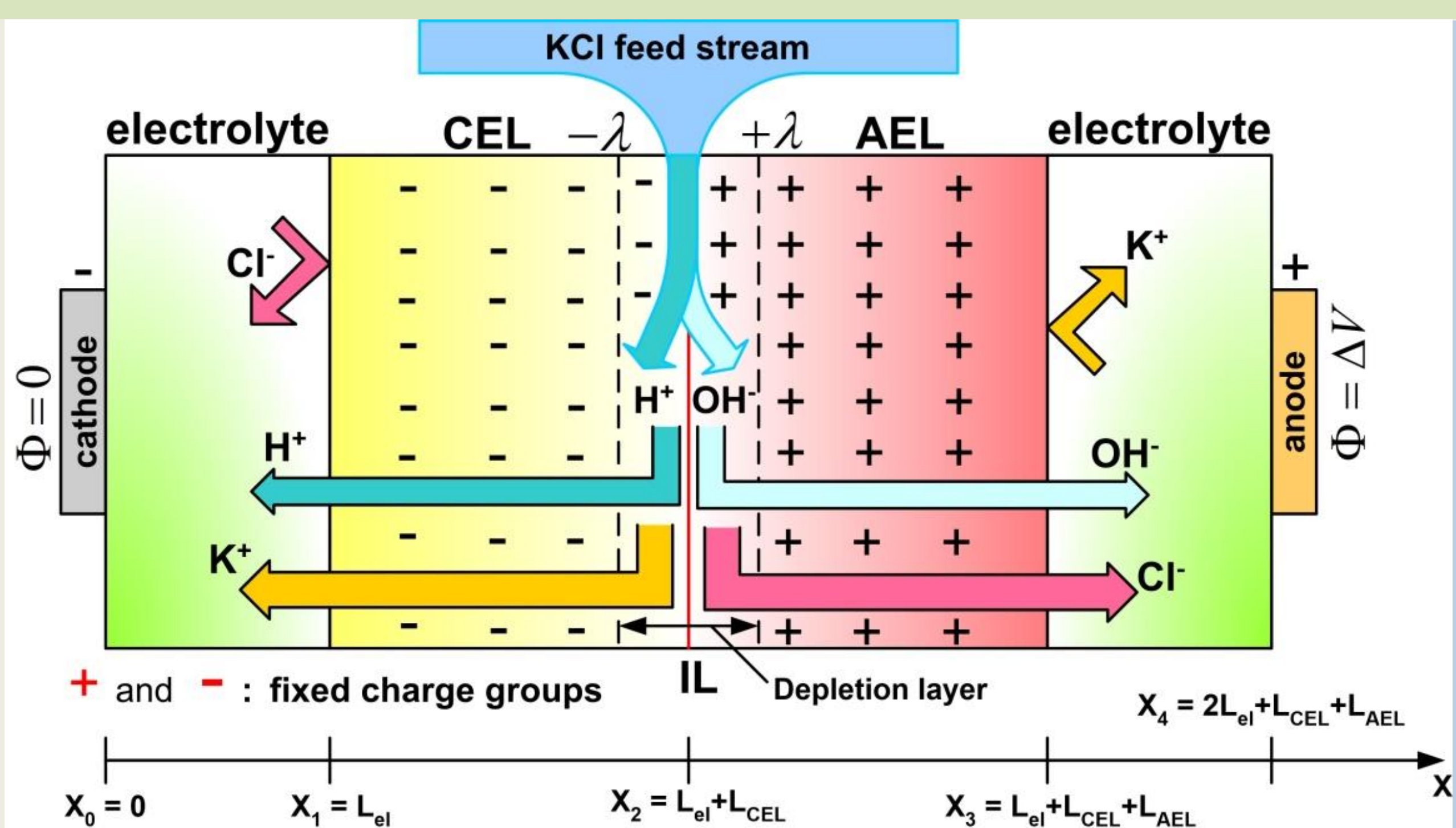


Fig. 1. Schematic representation for the operating principle of the bipolar membrane under reverse bias, considering water dissociation under the Wien effect with one-dimensional, non-stationary transport model

The potential jump at which will start the intense generation of  $H^+$  and  $OH^-$  ions,  $\Delta U_{diss}$ , is established under the second section length of the curve, as we can see in fig. 2. Water dissociation resistance,  $R_{diss}$ , is determined by the slope of the third section, representing the bipolar membrane's ability to enhance water dissociation: the smaller  $R_{diss}$ , the higher catalytic activity under water dissociation reaction.

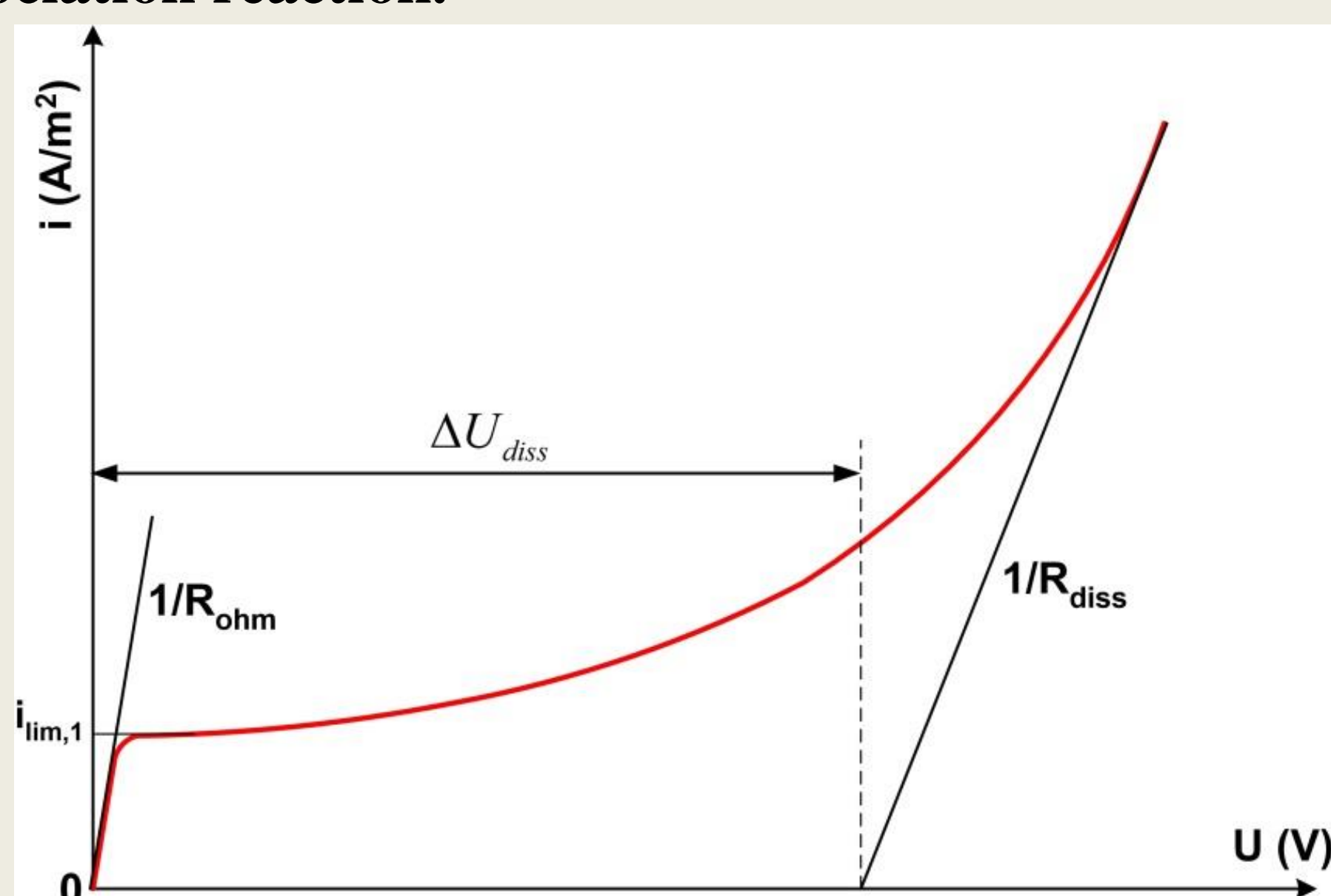


Fig. 2. Schematic current-voltage curve of a BPM in a salt solution

## 2. Simulation results

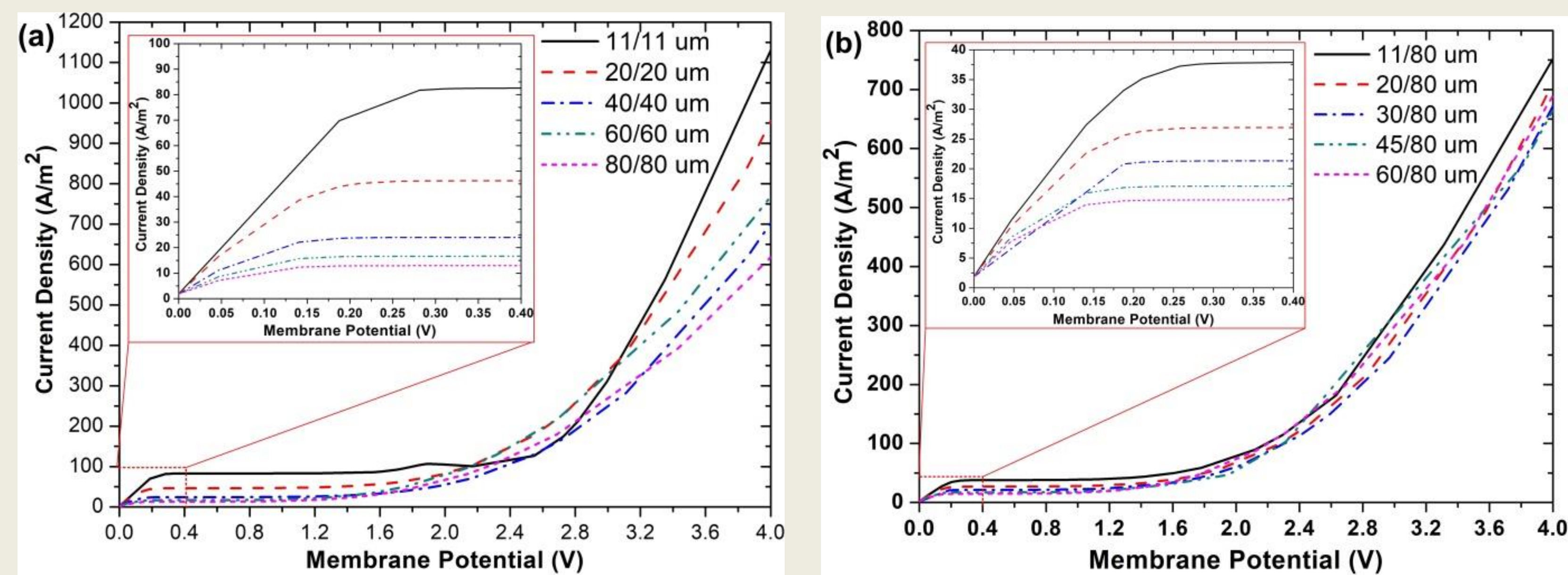


Fig. 3. Effect of modifying membrane thickness on the current-voltage curve of various BPM models: a) symmetrically and b) asymmetrically (just CEL)

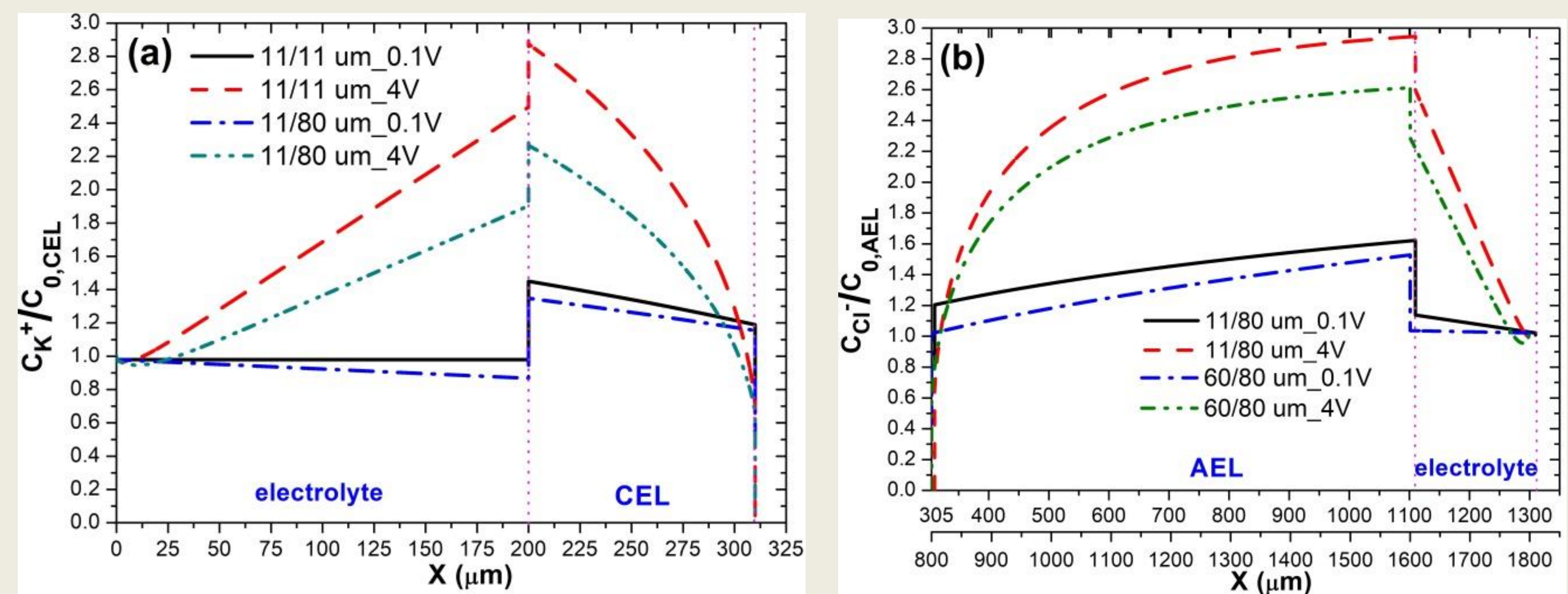


Fig. 4. Specific concentration ratio for the salt species across the electrolyte and CEL/AEL domains in the case of a) models 11/11  $\mu m$ , 11/80  $\mu m$  and b) models 11/80  $\mu m$ , 60/80  $\mu m$  simulated at two values of  $U_{bm}$  (V).

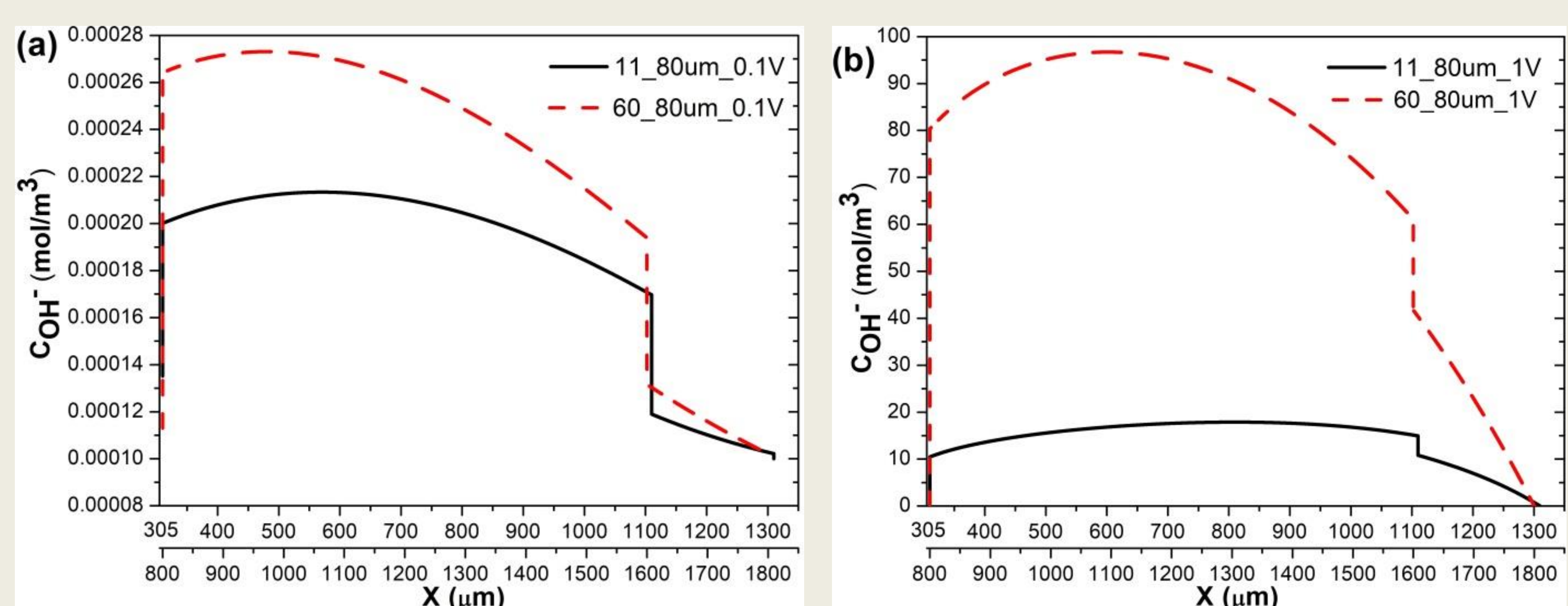


Fig. 5. Variations of  $OH^-$  ion concentration across AEL and electrolyte domains for the models with CEL/AEL thickness of 11/80  $\mu m$  and 60/80  $\mu m$  at  $U_{bm}$  values of a) 0.1V and b) 1V.

## 3. Conclusions

The increase of cation-exchange layer thickness from 11 to 60  $\mu m$  at a constant AEL thickness of 80  $\mu m$  and fixed charge concentrations of 1500  $mol/m^3$  played a minimal role in the electrochemical behavior of the bipolar membrane models. Instead, a simultaneous increase of CEL/AEL thickness from 11/11  $\mu m$  to 80/80  $\mu m$  significantly reduced salt-ion leakage currents, with the cost of about two times higher water dissociation resistance.

For the membrane potential drop between 0.1 and 1 V, an increase of over 80% of the current density was observed in the current-voltage curve of the model with ACL/AEL thickness of 11/80  $\mu m$  and fixed charge concentrations of 1500  $mol/m^3$ . This increase can be associated only with the diffusion transport enhancement of salt ions from the bipolar junctions towards anode/cathode and with co-ion leakage current increasing through the ion-exchange membranes.

## References

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