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Experiments and modelling for determining the Limiting Current Density in Electrodialysis units

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Introduction

A crucial parameter for the design and operation of electrodialysis (ED) units is the Limiting Current Density (LCD) which, according to the reference literature, depends mainly on concentration polarization. I-V curves obtained from measurements on electrochemical systems with electrodes in direct contact with the spacer, exhibit a plateau identifying the LCD. Differently, I-V curves of ED systems show more complex trends with a second change of slope where the current increases again (overlimiting). However, the LCD is assumed as a practical upper threshold for optimal operation in industrial units, because higher current densities may lead to a loss of efficiency. On the other hand, the determination of LCD in ED units is still ambiguous, although several methods have been proposed so far. In the present work, in order to explore such issues on the LCD identification, we performed in-situ measurements with ED units, assessing the influence of operating conditions and validating a purposely implemented process simulator, which was then used for further investigation.

Materials and Methods

A 10-cell pairs ED stack with a membrane active area of 10x10 cm^2 and equipped with woven spacers was tested. Inlet concentrations of NaCl ranging from 0.5 to 60 g/l (also considering different values for the two inlet streams) and inlet velocities in the range 0.25 – 2 cm/s were investigated. I-V curves were built by chronopotentiometric measurements. The process simulator is a one-dimensional semi-empirical model taking into account several non-ideal phenomena (osmosis, electro-osmosis, salt diffusion). The model predicts also concentration polarization by using Sherwood number values obtained from computational fluid dynamics simulations.

Results and Discussion

As a first finding, a lower threshold of the current density (*critical current*) was observed for all velocities: below this critical value, the outlet concentration is higher than the inlet concentration due to the osmotic and salt diffusion phenomena, while above, desalination is obtained (Fig. 1). The *critical current* changes with concentration difference between compartments, thus allowing to quantitatively characterise diffusion phenomena.

LCD is influenced by velocity but also by both streams concentrations (Fig. 2a): in fact, salinity in the concentrate compartment affects the diluate concentration (due to non-ideal phenomena such as diffusion and osmosis) and, consequently, also the LCD. Traditional graphical methods adopted to determine the LCD were compared with our method in which the current efficiency $\lambda = F\left(Q_{dil}^{IN}C_{dil}^{IN} - Q_{dil}^{OUT}C_{dil}^{OUT}\right)/I$ is plotted against the current density (Fig. 2b): this curve always shows a maximum value and we identify the corresponding current density as the LCD. Moreover, Fig. 2b identifies also the *critical current* density where $\lambda = 0$.

Interestingly, model predictions are always in good agreement with the experimental results as shown by continuous lines in Fig. 1.

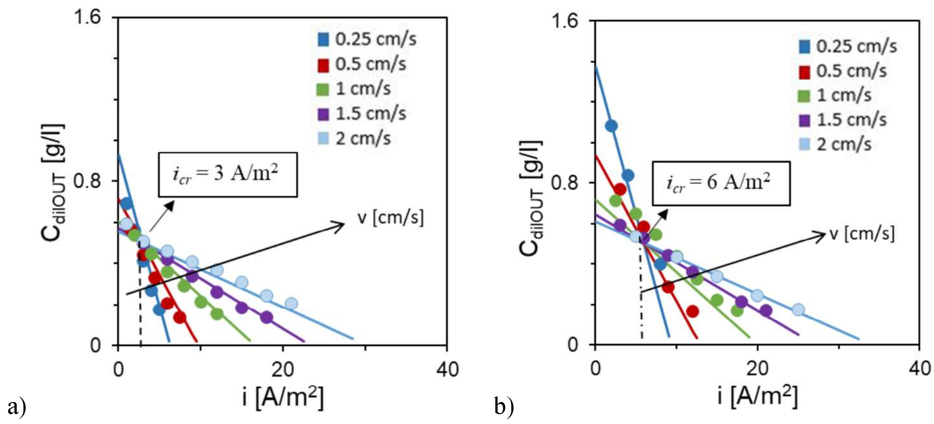

Figure 1. Outlet dilute concentrations vs Current density. Experiments (point) and model (lines) are compared. Five fluid velocities were examined. NaCl solutions of concentrations equal to 0.5 g/l in the diluate, and a) 30 g/l and b) 60 g/l in the concentrate. The *critical current* density is identified.

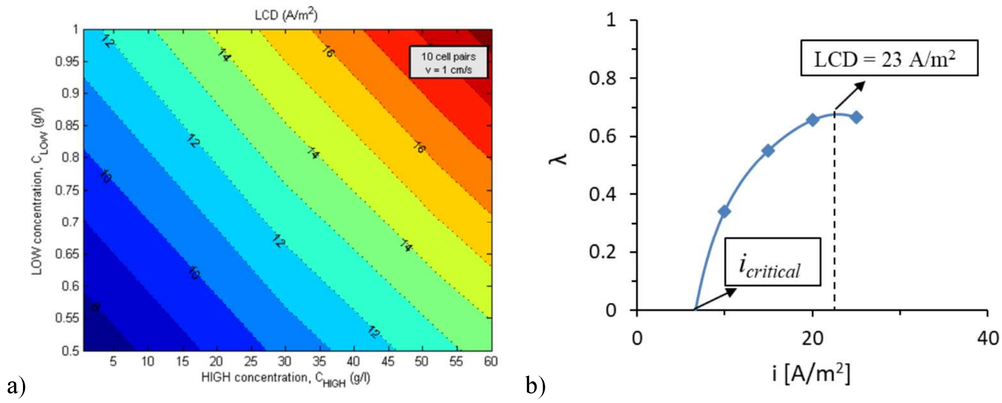

Figure 2. a) LCD as a function of both concentrations in the concentrate and diluate compartments. The velocity in the channels was 1 cm/s. b) Current efficiency vs Current density. Experiments (point) and best fit (lines). This graph was obtained with 60 g/l in the concentrate and 0.5 g/l in the diluate, with velocity equal to 2 cm/s. The LCD and *critical current* density are identified in b).

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