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Modelling of Electrodialytic Desalination of Regenerated Water Effluent with Byproducts Recovery

Juan Manuel Paz-García^{1*}, Elena Olivares-Ligero^{1,2}, María M. Cerrillo-González¹,
María J. Martínez-Salverri², Jose Miguel Rodriguez-Maroto¹, María Villén-Guzmán¹.

¹Departament of Chemical Engineering, University of Malaga (Spain)

²SANDO AGUA, Calle la Bohème 40, 29006 Malaga (Spain)

*juanma.paz@uma.es

1. Introduction

Electrodialytic desalination (EDD) is a promising technique for wastewater treatment that leverages an electric field to drive ion movement through ion-exchange membranes, efficiently removing salts and other impurities from water. This method has been successfully employed to produce water suitable for drinking and agricultural purposes. Compared to traditional methods like reverse osmosis, EDD offers the advantages of lower energy consumption and reduced chemical usage. Namely, EDD has not the problem of the generation of high concentrated salty water produced in the reverse osmosis treatment.

A model for EDD of brackish wastewater has been developed with the goal of reducing regenerated water conductivity to levels suitable for agricultural or recreative use in a single pass through a membrane system. Additionally, apart from generated the dilute stream, the cell design ensures that the separated ions generate valuable solutions in the auxiliary compartments. Specifically, a four-compartment cell has been conceptualized to prevent chlorine gas formation at the anode, instead producing either HCl or FeCl₃ and NaOH-rich solutions along with the diluted stream. This innovative design enhances the efficiency and sustainability of the EDD process.

FeCl₃ and FeCl₂ are typically used in wastewater for flocculation-coagulation in the primary and tertiary treatments. By means of a Fe⁰-based sacrificial anode, FeCl₃ and FeCl₂ can be produced during the EDD treatment and recuperated for direct use in the water treatment plant.

2. Experimental investigations

A 2D Tertiary Current Distribution (TCD) model has been implemented to simulate an electrochemical cell with four compartments. From left to right, the compartments are: (1) the anode and anolyte compartment, (2) the HCl or FeCl₃ concentration compartment, (3) the wastewater treatment compartment, and (4) the cathode and catholyte compartment. An anion-exchange membrane and a cation-exchange membrane are placed on the left and right sides of compartment 3, respectively. Additionally, a cation-exchange membrane is positioned between compartments 1 and 2 to prevent chloride ions from reaching the anode and producing chlorine gas. Figure 1 shows a schematic of the cell design.

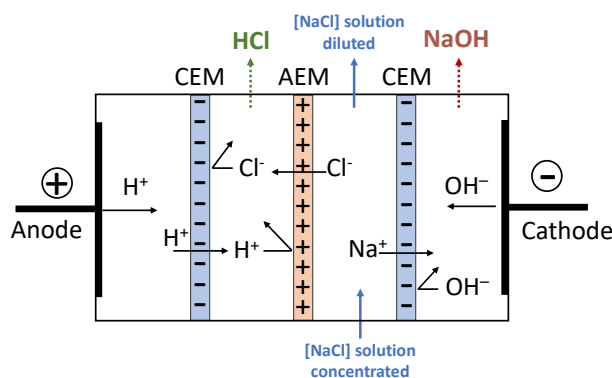


Figure 1. Schematics of a four-compartment EDD cell

The TCD model is solved considering the electroneutrality condition. Donnan boundary conditions are applied at each side of the ion-exchange membranes, which are modelled as thin, porous media with a fixed structural ionic charge. This detailed approach ensures accurate simulation of ion transport and electrochemical behaviour within the electrochemical cell.

3. Results

By adjusting concentration of inflows, applied electrical current and the flow rate of the different channels, it is possible to optimize the desalination process and the energy consumption. Results showed efficient NaCl concentration reduction in the wastewater effluent, and concentration of valuable HCl and NaOH solutions in the collecting compartments. To enhance reliability, the model was adjusted to work using chemical equilibrium reactions modelled as very fast reversible reactions. Water self-ionization was included in the model to monitor the corresponding acid and basic fronts generated at the anode and the cathode. Furthermore, the model shows the feasibility of producing FeCl_3 and FeCl_2 during the process.

4. Conclusion

The implemented model has demonstrated the theoretical feasibility of the technique and has been used for optimizing the cell geometry and fluid dynamics conditions to maximize the production of desired streams while minimizing energy consumption in lab-scale experiments. Future work will focus on validating the model with experimental data using actual wastewater effluent. Once validated, the model will be employed to design a pilot-scale cell for the desalination of high-conductivity wastewater effluent. The final goal is to develop a technique capable of conditioning wastewater effluent for agricultural use in the Costa del Sol region, thereby helping to alleviate water stress in the area.

Keywords: Multiphysics Modeling, Regenerated water, Electrodialytic water treatment, Ferric oxide generation.

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