المدرسة الوطنية للمهندسين بقابس

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MODELING AND SIMULATION OF A MICROBIAL DESALINATION CELL

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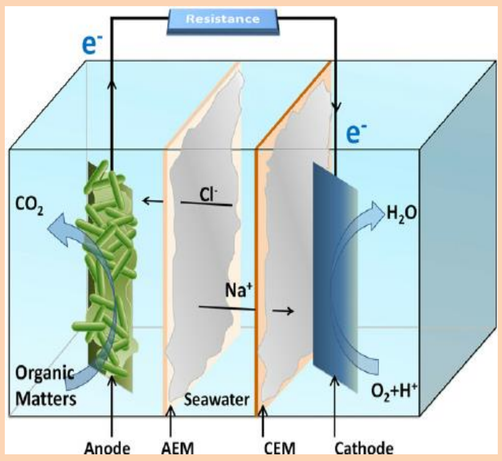
Abstract

The challenge of providing safe drinking water is further complicated by population growth, industrialization, contamination of available freshwater resources, and climate change. Despite major advancements in desalination technologies, seawater desalination is still more energy intensive compared to conventional technologies for the treatment of fresh water. There are also concerns about the potential environmental impacts of large-scale seawater desalination plants. Microbial Desalination Cell (MDC) is a newly developed technology considered a low-energy-consumption, clean technology to simultaneously purify wastewater and desalinate saline water by using the in situ energy source contained in wastewater. The principle of MDC is to use electricity-generating bacteria to consume organic matters in water and create an electrical field that separates salts in saline water.

A microbial desalination cell proposed in the framework of the European MIDES project was modeled and simulated. The result shows the feasibility of the coupling of waste water treatment and water desalination which improves the performance of this unit.

Typical scheme of microbial desalination cell [Q.Ping et al., 2013]



MDC consists of three chambers, an anode, middle (saline water), and a cathode, separated by an anion exchange membrane (AEM: between the anode and the middle chambers) and a cation exchange membrane (CEM: between the cathode and the middle chambers), respectively

CDM Modeling and electricity Generation

Electricity Generation

$$V_{jct} = \frac{RT}{F}\left|\Sigma_{ION} * \frac{T_{MEA,ions}}{Z_{ion}} Ln\left(\frac{a_{ion,m}}{a_{ion,a}}\right)\right| + \frac{RT}{F}\left|\Sigma_{ION} * \frac{T_{MEC,ions}}{Z_{ion}} Ln\left(\frac{a_{ion,m}}{a_{ion,c}}\right)\right|$$

osmotic pressures (Van't Hoff's)

$J_{w,a} = A_{MEA} * RTI * (C_{sel,m} - C_{sel,a}) / 2$

$J_{w,c} = A_{MEC} * RTI * (C_{sel,m} - C_{sel,c}) / 2$

diffusion profile

$D_{res,a}$ = [arctan ((Csel, m-Csel, a) /2.50) -pi) + arctan (pi)

$D_{res,c}$ = [arctan ((Csel, m-Csel, c) /2.50) -pi) + arctan (pi)

CDM Modeling

$$\frac{dCsel,m}{dt} = D_{sel} * C_{sel,in} - \frac{(Q_{sel} + J_{w,a} + J_{w,c})}{V_{sel}} * C_{sel,m} - 2 * \frac{I_{CDM}}{F * V_{sel}} * \alpha - 2d * D_{res,a} - 2d * D_{res,c}$$

$$\frac{dCsel,a}{dt} = D_{anode} * C_{sel,a,in} - \frac{(Q_{anode} - J_{w,a})}{V_{anode}} * C_{sel,a} + 2 * \frac{I_{CDM}}{F * V_{anode}} * \alpha + 2d * D_{res,a} * \frac{V_{sel}}{V_{anode}}$$

$$\frac{dCsel,c}{dt} = 2 * \frac{I_{CDM}}{F * V_{cathode}} * \alpha + 2d * D_{res,c} * \frac{V_{sel}}{V_{cathode}}$$

$$\frac{dC_{ion,m}}{dt} = D_{sel} * C_{ion,in} - \frac{(Q_{sel} + J_{w,a} + J_{w,c})}{V_{sel}} * C_{ion,m} - \varphi_{ion} * \left[\frac{I_{CDM}}{F * V_{sel}} * \alpha + d * D_{res,a} + d * D_{res,c}\right]$$

Simulation results

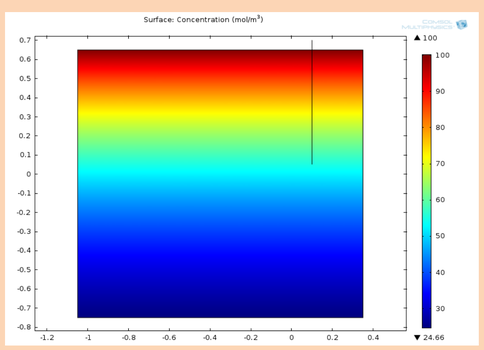


Figure 1. Variation of the concentration in the electrochemical reactor

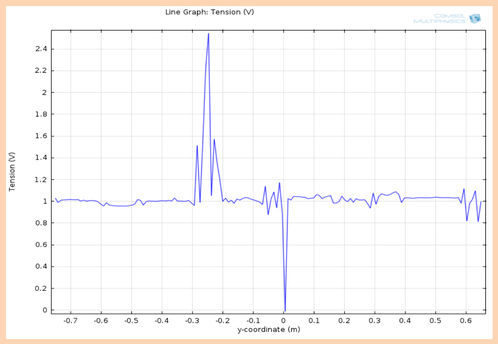


Figure 2. Variation of the voltage as a function of the position in the reactor

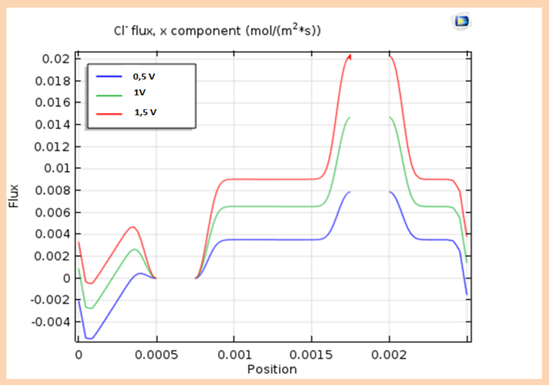


Figure 3. Variation of the flux density of Cl^- in the cell as a function of the electrode position for different voltage

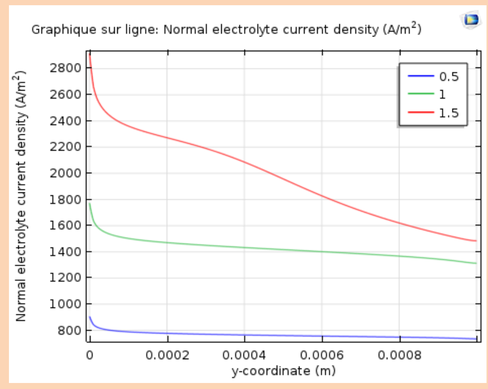


Figure 4. Variation of the current density throughout the membrane (for different voltages)

❑ Figure 1 shows a concentration gradient in the reactor. The concentration throughout the reactor drop gradually, following the oxidation of organic material. This degradation of the organic material is accompanied by generation of electrons which will be captured by the anode thus producing an electric current which will be used later in the membrane.

❑ Figure 2 shows that the potential present a negative peak near the anode (y = 0). This peak can be explained by the rapid migration of electrons towards the anode, which induces a failing electron medium. On the other hand the appearance of a positive potential a little further towards the bottom of the reactor may result from a recombination phenomenon of the electrons with the organic material.

❑ The density of the Cl^- flow all along the cell increases as a function of the voltage. Indeed, when the voltage imposed at the membrane increases the rate of migration of ions increases. The process of migration is due to a potential difference and is accompanied by the diffusion of matter due to a difference in concentration (figure 3).

❑ The electric current density increases as a function of the imposed potential. For the 3 potentials, the density of the current drops throughout the membrane (from bottom to top). The gradient of the concentration becomes more and more important towards the exit of the reactor. For Y = 0 the current consumed is important as Cl^- ions are located away from the membrane. For Y = 1m (at the output) the diffusion process is established and a quantity of Cl^- is located near the membrane which makes the current consumed lower (figure 4).

Conclusion

The microbial desalination cell (MDC) is an emerging concept for simultaneous wastewater treatment and water desalination. The principle of MDC is to use electricity-generating bacteria to consume organic matters in water and create an electrical field that separates salts in saline water. In this study, a mathematical modeling and simulation study of a microbial desalination cell were performed using *COMSOL Multiphysics*. The results obtained allowed us to show:

- The variation of the concentration of organic matter in the reactor according to the place of feeding,
- The effect of the position of the electrode in the reactor on the generation of the voltage,
- The variation of the density of the electric current throughout the membrane (The density of the current decreases from the bottom to the top of the reactor when the cell is fed from the bottom)

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