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Scientific paper
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Desalination of brackish water using electro dialysis: Effect of operational conditions

As the most countries on the earth, shortage of drinking water is a major problem in Tunisia. One mean to obtain low cost drinking water is the desalination of brackish water. The desalination of brackish water by electro dialysis was investigated in this work. This technique is a membrane separation process based on the selective migration of aqueous ions through ion exchange membranes as a result of an electrical driving force. It represents one of the most important methods for desalting solutions as well as thermal process and reverse osmosis.

The parameters which can influence the performance of process were studied. These parameters are: concentration of feed solution, flow rate, voltage and circulation mode. Experiments were carried out on sodium chloride solutions with known concentration. Working in continuous mode showed that the desalination rate does not exceed 55%. However, working in batch recirculation mode, more efficient results were obtained. An initial concentration of 3 g L⁻¹ of salts is considered as the maximum recommended feed concentration.

Key words: Brackish water, Desalination, Electro dialysis, Optimal conditions

INTRODUCTION

Source waters include ocean waters and numerous inland sources of saline water, such as geothermal, brackish ground and surface water (water with less than 10 000 milligrams per litre of total dissolved salts), and wastewater. In Tunisia, The traditional sources of fresh water are limited in capacity and are being stressed by competing uses, such as irrigation and industrial needs.

In recent years, there has been an increasing interest in using brackish waters as a source of potable water. The utilities of brackish water are increasing with the development of desalination processes. These processes create more valuable water by converting saline waters into a resource. Additionally, desalting processes can be used in industrial applications to produce ultrapure water or process water of very high quality, thereby greatly enhancing the productivity of numerous industries, including electronics, pharmaceuticals, power, food and beverage, mining, refining, and paper industries [1-3].

There are basically two families of desalination technologies used throughout the world today. These include thermal technologies and membrane technologies [4]. Thermal technologies are those that heat water and collect condensed vapor (distillation) to produce pure water. Rarely distillation processes are used to desalinate brackish water, as it is not cost effective for this application. Membrane technologies are much younger in their development than thermal processes. It uses membranes to separate the feed stream into two streams of differing concentration, a product and concentrate stream. For desalination, membrane technologies include mainly Reverse osmosis (RO) and Electro dialysis (ED) [5].

Electro dialysis is mainly based on selective movement of ions in solutions as a result of an electrical driving force. It is used to remove ionized substance from liquids through selectively ion permeable membranes [6-10]. This chemical-free technology competes with reverse osmosis. It shows better resistance to fouling and scaling [4]. It also has an economical advantage in desalination of low Salinity solution (less than 5 g L⁻¹ as total dissolved salts TDS) [5]. Also it should be kept in mind that because of low chemicals consumption, ED is an environmental friendly process for solution desalination [11].

The mandatory condition for an electro dialysis process to be executed is an alternating order of cation and anion membranes and electric field applied across the entire assembly (Fig. 1). When a direct current is imposed on the solution, the positive ions

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migrate to the negative electrode, or cathode. The negative ions migrate to the positive electrode, or anode. A cation permeable membrane allows positive ions to pass, but blocks negative ions. An anion permeable membrane does the opposite. It allows negative ions to pass, but blocks positive ions.

The two types of membranes create alternately two compartments. These compartments will accumulate the ions because the ion exchange membrane between them would prevent ions from moving further. Therefore the solution in the even compartments (1) will be demineralised and solution in the odd compartments (2) will be concentrated. As a result the entire flow incoming to the electrodialysis apparatus can be separated into desalinated and concentrated streams. These flows are called respectively dilute and concentrate.

In This paper, the demineralization of brackish water by this process was investigated. The parameters that can affect the process efficiency were studied. These parameters are: concentration of feed solution, flow rate, applied voltage and circulation mode. This in order to determine the optimum conditions to obtain potable water from brackish one.

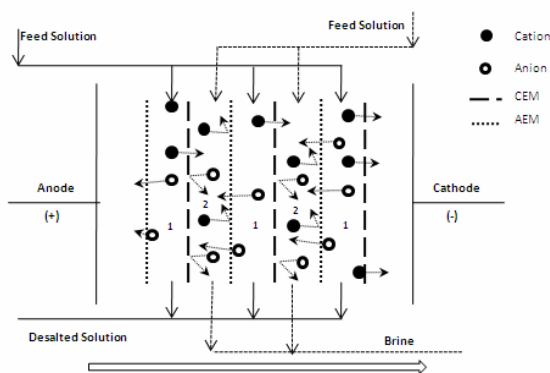


Fig. 1: Principle of electrodialysis

MATERIALS AND METHODS

Electrodialysis equipment and membranes

The ED setup consists of: a power DC, a brine tank, a feed tank, an electrode rinse tank, three centrifugal pumps ($P = 84W$, total head = 4.2 m) equipped each with a flowmeter and three valves to control feed flow rate in the compartments of ED cell. Fig. 2 shows a simplified diagram of the ED setup working in continuous and recirculation mode.

The electrodialysis operation was carried out on a laboratory stack "PCCell ED 64 002" supplied by PCA-Polymerchemie Altmeier GmbH and PCCell GmbH, Heusweiler, Germany. ED cell is packed with ion exchange membranes (cation and anion), spacers and a pair of electrodes (anode and cathode). Both

electrodes are made of Pt/Ir- coated Titanium. The membranes and spacers are stacked between the two electrode-end blocks. Plastic separators are placed between the membranes to form the flow paths of the dilute and concentrate streams.

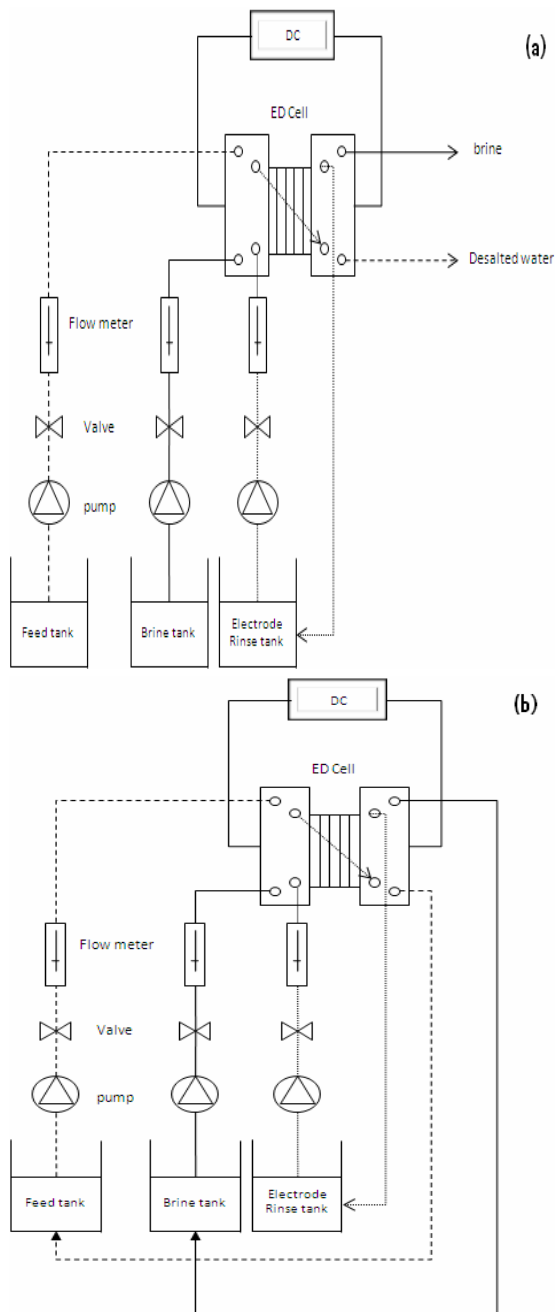


Fig. 2: Schematic of the ED system used in this study
(a) continuous mode (b) batch recirculation mode

These spacers are designed to minimize boundary layer effects and are arranged in the stack so that all the dilute and concentrate streams are manifolded

separately. In this way a repeating section called a cell pair is formed; it consists of a cation exchange membrane, a dilute flow spacer, an anion-exchange membrane, and a concentrate flow spacer. In this work, experiments were carried out by this stack equipped with three cation exchange membranes (CEM) and two anion exchange membranes (AEM) arranged as described in fig. 3.

For each membrane, the active surface area is 0.0064 m² and the flow channel width between two membranes is 0.5 mm.

PCA-SK standard cation exchange membranes and PCA-SA standard (SA) anion exchange membranes are used in the stack. Information about the membranes is given in Table 1, which was

supported by the manufacturer. The ED system is designed to handle 2-5 L laboratory batches.

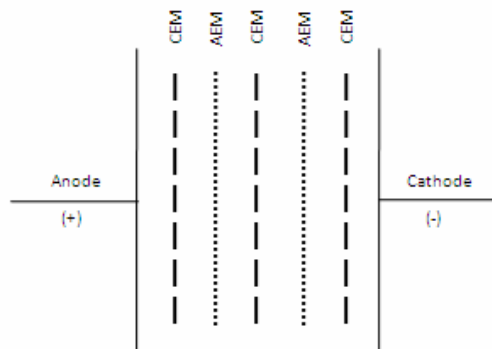


Fig. 3: ED cell setup

Table 1 - Information on PCA standard cation and anion exchange membranes

Membrane	Thickness (µm)	Ion exchange capacity (mequiv. g ⁻¹)	Chemical stability (pH)	Permselectivity	Functional groups	Surface potential (Ω cm ²)
PC-SK	130	ca. 1	0–11	>0.96	–SO ₃ Na	0.75–3
PC-SA	90–130	ca.1.5	0–9	>0.93	–NR ₄ Cl	1–1.5

Reagents

Analytical grade sodium chloride and sodium sulfate salts are used in all experiments to produce solutions with known total dissolved salts (TDS) and electrode rinse solution. Distilled water was used throughout.

EXPERIMENT AND ANALYSIS METHODS

Experimental procedure

During the experiments, the volume of dilute, concentrate and electrode rinse solution was 5 L. As initial concentrate and dilute, the same solution was used. As electrolyte solution circulating in electrode compartments (electrode rinse solution), 0.1 M Na₂SO₄ was used.

Total voltage drop, including voltage drop in the membrane stack as well as on the electrodes, was measured in the experiments. Flow rate of dilute and concentrate were fixed at the beginning of experiment; flow rate of electrode rinse solution was 80 L h⁻¹. Prior to the experiments, pH was corrected by HCl or NaOH. In each experiment, the initial pH was adjusted to 7.

Analytical methods

The electrical conductivity (EC) and temperature of samples taken from the diluate and concentrate during each experiment was measured using a 712 Conductometer (Metrohm AG, Switzerland).

Data analysis

The purpose of the experiments was to study the effects of voltage, flow rate, circulation mode and concentration on ED cell performance.

All figures and tables refer to concentration changes in the dilute. The mass balance of the ions present in the feed solution was verified for dilute, concentrate and electrode rinse solution. Thus, data for concentrate and electrode rinse solution will not be presented in this article.

In this study, the quality characteristic was the separation percentage (SP) which was calculated as follows:

$$SP(\%) = \left(1 - \frac{C}{C_0}\right) \cdot 100$$

Where, C₀ and C are feed and dilute concentrations, respectively.

The conductivity was measured using a conductometer (Metrohm, 712 Conductmeter) in order to determine the concentration of ions in the dilute.

RESULTS AND DISCUSSIONS

Effects of applied voltage on SP

To study the effect of applied voltage, the concentration of feed solution and the real inlet velocity were fixed respectively to 1 g L⁻¹ and 15 L h⁻¹.

The influence of applied voltages on the separation percentages is illustrated in fig. 4.

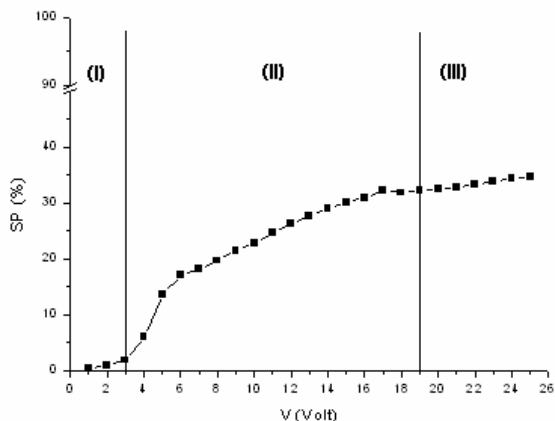


Fig. 4: Effect of applied voltages on the separation percentage

Fig. 4 shows that the separation percentage increases with an increase of voltage. There are three distinguished parts in this curve. In the first part (indicated by I) the separation percentage increases only marginally with the increasing voltage drop. Figure 5 which illustrate the evolution of the resistance of electro dialysis stack ($R=V/I$) as function of the applied voltage, shows that in this region the resistance of the stack is relatively high. This phenomenon can explain the low SP obtained. In fact at these conditions there are a few transports of ions between the dilute and concentrate compartments. The applied voltage is not so important to overcome the resistance of membranes and to induce the transport of several ions.

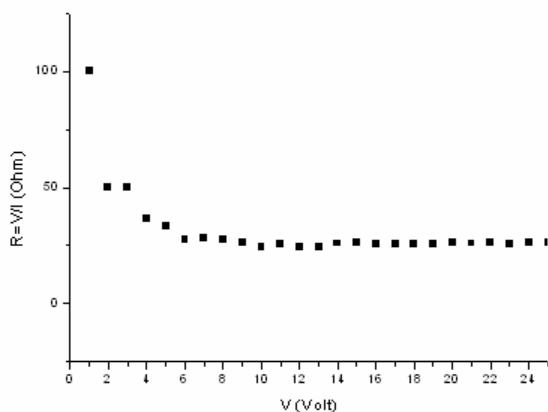


Fig. 5: Resistance of electro dialysis stack as function of the applied voltage

In the second part (indicated by II), fig. 4 shows a more or less linear increase of the SP versus voltage. At the same region, figure 5 shows that the resistance of the stack is quasi-constant. The current increase linearly with an increase of the applied voltage

according to Ohm's law. The transport of ions between the compartments of cell is proportional to current. These can explain the proportionality between SP and the applied voltage.

In the third part (indicated by III), the increase in the applied voltage does not lead to a significant increase in the SP. At this point the limiting current density is reached and there is no increase in the current density neither ionic transport from dilute to concentrate compartment when the applied voltage increases.

Effects of flow rate on SP

The flow rate of dilute compartment was varied from 5 to 30 L h⁻¹. The flow rates of the other solutions (concentrate and electrode rinse compartments) were 30 L h⁻¹. The concentration of feed solution was fixed at 1 g L⁻¹. 10 V was applied across the entire assembly.

The influence of the flow rate on the separation percentages measured is illustrated in Fig. 6. We notice that the separation percentage decreases with an increase of the flow rate. This can be explained by the remaining time of ions inside the different compartments of the cell. In fact the ions have more time to be transferred from one compartment to another through the membrane when the velocity or flow rate is lower. This can lead to an increase of the total amount of salts transferred and consequently to an increase of separation percentage. For that, low flow rates are recommended to get maximum separation.

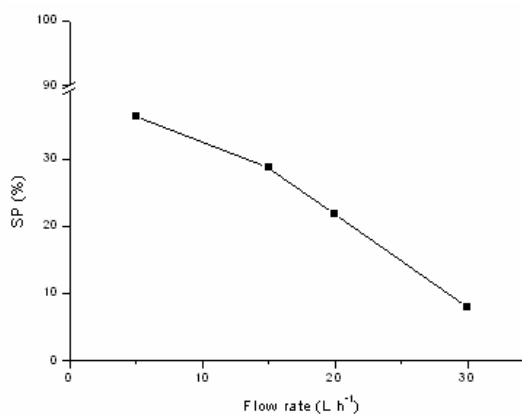


Fig. 6: Effect of flow rate on the separation percentage

Effects of initial feed concentration on SP

The flow rate of dilute and concentrate were fixed respectively to 15 L h⁻¹ and 30 L h⁻¹. The concentration of feed solution was varied from 1 to 3 g L⁻¹. 10 V was applied across the entire assembly. Fig. 7 represents the variation of the separation percentage

as function of initial feed solution concentration. It shows that the separation percentage have a considerable dependence with the feed solution in this range of concentration. In fact at the some hydrodynamique and electrical conditions, the number of ions transported through the membranes are almost the same but total amounts of salts is quite different from the different treated solution. As known the calculation of SP depends strongly on the initial feed concentrations and the amount of transported ions. So the SP evolves reciprocally to the initial feed concentration at the some hydrodynamique and electrical conditions. Some experiments were performed for solution over 3 g L^{-1} of salts.

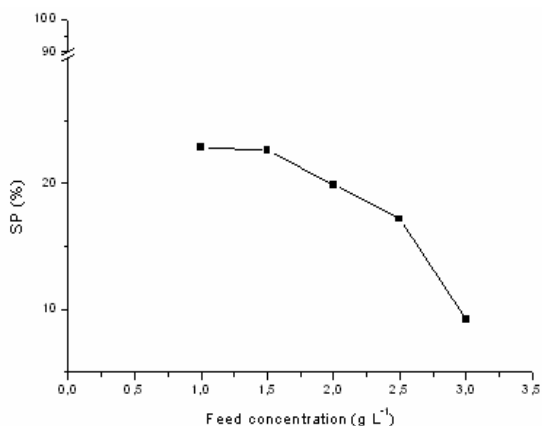


Fig. 7: Effect of the initial feed concentration on the separation percentage

The separation percentage was very low and insignificant. Also some problems, such an increase of temperature in electrodes compartments, were resulted at high applied voltage. For these reasons it is suitable to use this process for the demineralization of solution with salinity under 3 g L^{-1} .

Effects of circulation mode on SP

The set of primary tests was done to determine the limiting current density for the operating conditions. The limiting current (LC) was determined experimentally for several feed concentration by plotting the electrical resistance across the membrane stack against the reciprocal electric current. This is called a Cowan–Brown plot after its original developers [6, 12]. The flow rate of dilute solution was fixed to 5 L h^{-1} .

The ED treatment was carried out in concentrate and dilute recirculation mode and continuous mode as indicated in fig. 2 (b).

Table 2 shows the effect of the circulation mode on the separation percentage at different feed concentration. We notice that separation percentages surpass 80% in the case of recirculation mode and do not exceed 55% in continuous mode

Table 2 - Effect of the circulation mode on the separation percentage

Concentration (g L ⁻¹)	Limiting current (A)	SP (%) continuous mode	SP (%) recirculation mode
1	0.57	54.87	91.36
2	0.93	39.77	86.23
3	1.16	42.38	80.45

CONCLUSION

The characterization of an ED plant by means of the determination of the working optimum conditions (applied voltage, flow rate and circulation mode) is an effective tool to operate in the most suitable efficient conditions.

This characterization can be effectuated by the determination of separation percentage versus applied voltage in the continuous mode and versus time when working in recirculation mode.

The characterizations were accomplished by the use of standard aqueous solutions of NaCl. The study

reveals the existence of a maximum separation percentage.

For a low salinity range ($1\text{--}3\text{ g L}^{-1}$), the increase of applied voltage can increase the separation percentage but it is suitable to work below limiting current conditions to avoid loss of energy efficiency. This study showed also that low flow rates are appropriate in continuous mode.

However the maximum separation percentage does not exceed the 55% in all ways. On the other hand, working in recirculation mode, more demineralization rates are obtained (more than 80%).

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