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# Current-Voltage Curves for Aqueous Solutions of Nacl: Determination of the Limiting Current

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**ABSTRACT:** The demand for drinking water leads to find new water resources and treatment technologies. The desalination of brackish water by electrodialysis is a good alternative, and for the process to be efficient, the limiting current density must first be known. The aim of this study was to determine the limiting current density and the effect of the volumetric feed flow on the limiting current density, for a 1000mg.$L^{-1}$ aqueous NaCl solution, in an electrodialysis module at laboratory scale. Experimental tests were performed at different volumetric feed flows of 200, 400 and 600 mL.$min^{-1}$. The results demonstrated a direct relationship between the limiting current density and the volumetric feed flowlikewise; the limiting current density of the anion exchange membrane conditioned the process.

**Keywords**: Electrodialysis, ion exchange membrane, current-voltage curve, limiting current density.

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## I. INTRODUCTION

The shortage of freshwaterand pure will be one of the main challenges to solve in this century. 98% of the water on the planet comes from sources such as oceans, seas and deep underground deposits that are not fit for human consumption. The demand for water shall beincreasing in the productive sectors, especially in agriculture and industry (Swain, 1998). Some countries face difficulties in supplying drinking water to the population due todifferent causes such as rapid population growth, industrialization, climate change caused by lack of rain and pollution of underground and surface water resources (Hadadin, Qaqish, Akawwi&Bdour, 2010; Shamsuzzoha, Rasheduzzaman& Ghosh, 2018; Mapunda, Chen & Yu, 2018; Rocha-Melognoet al., 2018). Another cause is the lack of proper management despite the fact that the country has abundantwater resources (Ayoub, 2006).

The salinity of seawater is due to the amount of mineral salts present. The main compound that makes saline in seawater is NaCl. Desalination or also called desalting is presented as a solution for the production of drinking water because it reduces the amount of dissolved salts that may be in saltwater, in addition, it is increasingly possible to decrease the high costs that associate it through the use of sources of clean energy (Moya, 1997). There are several methods to desalinate saltwater, among the main ones are: multi-effect distillation, multi-phase flash distillation, steam compression distillation, reverse osmosis and electrodialysis (Al-Shayji, 1998).

Electrodialysis(ED) is an electrochemical process that separates ions from a solution through ion exchange membranes (IEM) under the influence of a continuous electric field (Sadrzadeh&Mohammadi, 2008). The ED process has a lot of application in the desalination of brackish waters, so that the ED process is a success, the studies focus on the design and optimal operation of theED equipment at laboratory, pilot or industrial scale (Gmaret al., 2017; Chehayeb, Farhat, Nayar&Lienhard, 2017; Xu et al., 2018; Wright, Shah, Amrose& Winter, 2018). The performance of thisED process was determined by critical design parameters, such as the volumetric flow of fluid inlet, compartment spacing and the design of the module. These parameters affect both the limit current density and the process costs (Lee, Strathmann& Moon, 2006).

One of the most important phenomena that occursduring the ED process, specifically, in the membrane-solution interfaces, is concentration polarization, which is related to the limiting current density (Sata, Yamane &Mizutani, 1969). The limiting current is the maximum electric current that can be used in the ED process when it exceeds its value it can cause phenomena such as water dissociation, which is not desirable for the process (Medina, 2011). The limiting current can be determined using the current-voltage curve(CVC) method that has been given a lot of attention in the field of IEM (Valerdi-Pérez & Ibáñez-Mengual,

2001; Fu, Xu, Yang & Pan, 2005 ;Kharina, Kabanova&Eliseeva, 2014). The method consists in the construction of a graph characterized by three distinct regions such as the ohmic, plateau and overcurrent (Kánavová, Machuca&Tvrzník, 2014; La Cervaet al., 2018), as shown in Figure 1.

The first region is governed by Ohm's law, also called the ohmic region, due to the resistivity of the electrolyte and membrane. The second region is characterized by a plateau as a result of the decrease in the number of ions in the layer adjacent to the membrane surface. In the third region another increase in current is observed, this time above the limiting current. The value of the limiting current is determined by the intersection of the tangents to the curves of the ohmic and plateau regions. (Kánavováet al., 2014; Scarazzato, Buzzi, Bernardes, Tenório& Espinosa, 2015).

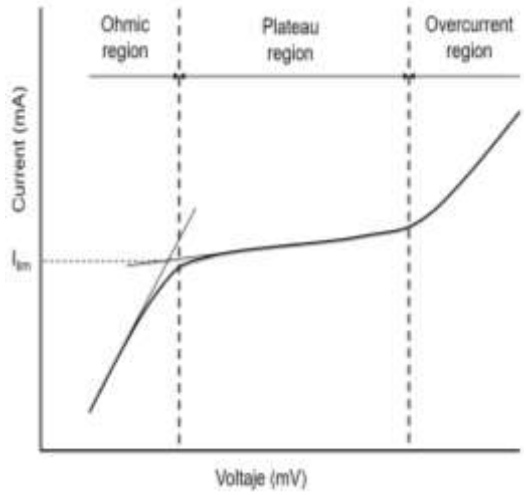



**Figure 1.** Typical current-voltage curve with its three regions and limiting current.

The present study aims to determine the limiting current of an aqueous NaCl solution with a concentration of 1000 $mg.L^{-1}$using an ED module and the effect of the volumetric feed flow on the limiting current.

## II. MATERIALS AND METHODS

To determine the limiting current, anED module operated in batch mode with recirculation, at laboratory scale, was used with a five-compartment cell. Inside the ED cell, two cation exchange membranes (CEM) and two anion exchange membranes (AEM) were placed, all with a 16 $cm^2$ working area alternated with each other using the CEMAEMCEMAEMconfiguration.Thecharacteristics of the membranes are presented in Table 1.

**Table 1.** Characteristics of the membranes.

| Membrane | FKB-PK-130 | FAB-PK-130 |
|---|---|---|
| Type | Cation exchange membrane | Anion exchange membrane |
| Thickness (dry), µm | 126-140 | 122-133 |
| Ion exchange capacity, $meq.g^{-1}$ | 0.9 | 0.8 |
| Specific conductivity, $mS.cm^{-1}$ | 4.0 | 3.6 |
| Resistance to the area, $\Omega.cm^2$ | 3.27 | 3.51 |
| Selectivity, % | 98 | >95 |

Source: Technical Data Sheet - fumasep FKB-PK-130 and FAB-PK-130, Germany.

In each of the diluted and concentrated containers, 1000 mL of aqueous NaCl solution was added at a concentration of 1000 $mg.L^{-1}$ as the working solution. An aqueous solution of $Na_2SO_4$ at a concentration of 3550 $mg.L^{-1}$ was added to another container to maintain the conductivity and wash the electrode compartments of the ED cell.Commercial titanium electrodes such as anode and cathode were use in the ED cell. Three pumps were used for the circulation of the aqueous solutions in the hydraulic system of the ED module. A DC power supply was used to apply the continuous electric current. To have a good precision and accuracy of the measurement, the system was monitored with multimeters. The Figure 2 shows the arrangement of the components (containers, pumps, ED cell, and power supply) of the ED module.

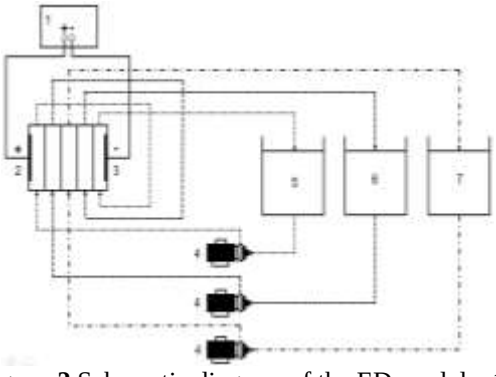


**Figure 2.**Schematic diagram of the ED module. 1: DC power supply; 2: anode; 3: cathode; 4: pump; 5: $Na_2SO_4$ aqueous solution container; 6: NaCl aqueous solution container (concentrate); and 7: NaCl aqueous solution container (diluted).

The current passing through the ED cell and the potential of theCEM and AEM located in the center of the ED cell were measured with three digital multimeters (CD771, Sanwa, Japan). The potential membrane was measured by two platinum

wires placed between each side of the membrane, as shown in the schematic drawing of Figure 3.

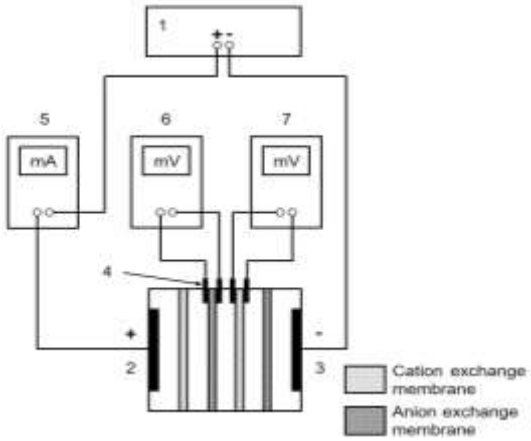



**Figure 3**. Schematic diagram of the arrangement of the measuring instruments. 1: DC power supply; 2: anode; 3: cathode; 4: platinum wires;5: multimeter (current); 6 and 7: multimeter (potential).

To obtain a CVC, the prepared aqueous solutions were circulated through the hydraulic system of the ED module. The DC power supply and multimeters were turned on, then a potential was set for 2 minutes. After this time, the CEM and AEM potentials and the current were recorded and then the DC power supply was turned off for 3 minutes and then turned on again, increasing the potential and repeating the previous steps until reaching the maximum potential of the DC power supply. The Figure 4 shows the flow chart of the procedure for obtaining the CVC. Thisprocedure has been used by other researchers (Scarazzatoet al., 2015).

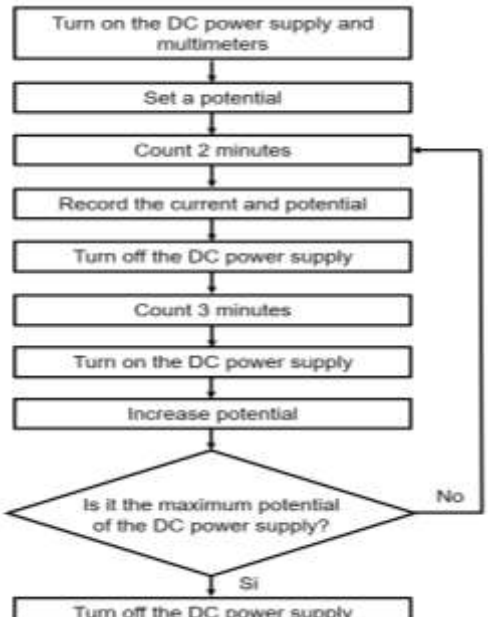
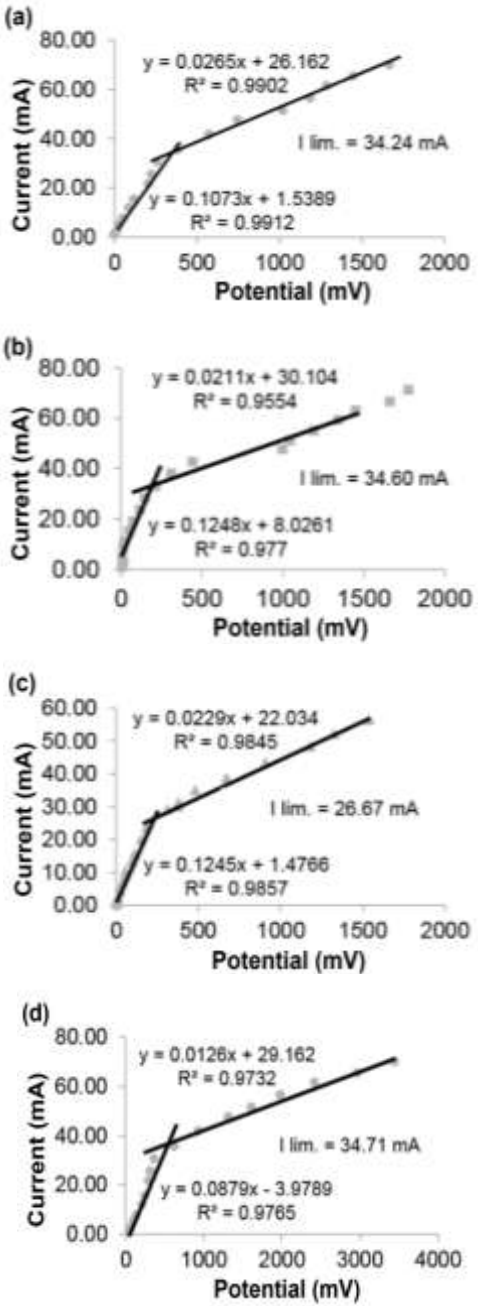



**Figure 4.** Flow chart of the current and potential measurement procedure to obtain the CVC.

## III. RESULTS AND DISCUSSION

Figures 5, 6 and 7 show the CVC for CEM and AEM at different volumetric feed flows. The limiting currents were determined as a result of the intersection of the tangents of the first and second regions of each CVC.Three replications were made for each volumetric feed flow and its average was divided by the working area of the membrane that was 16 $cm^2$.



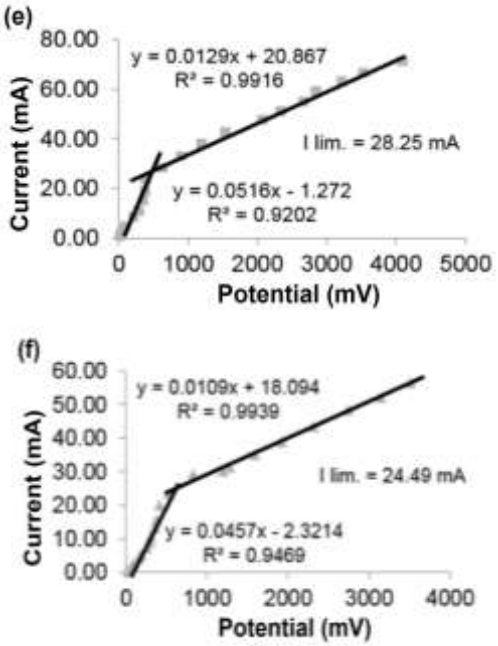
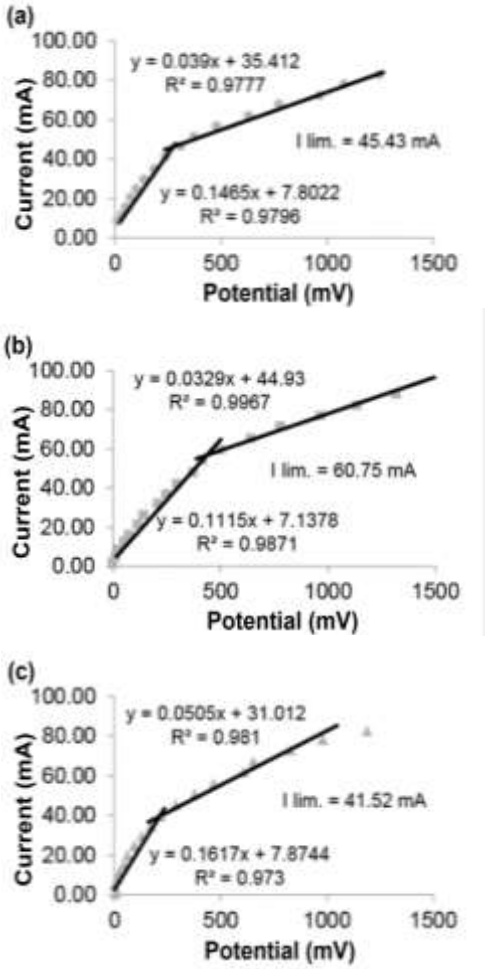
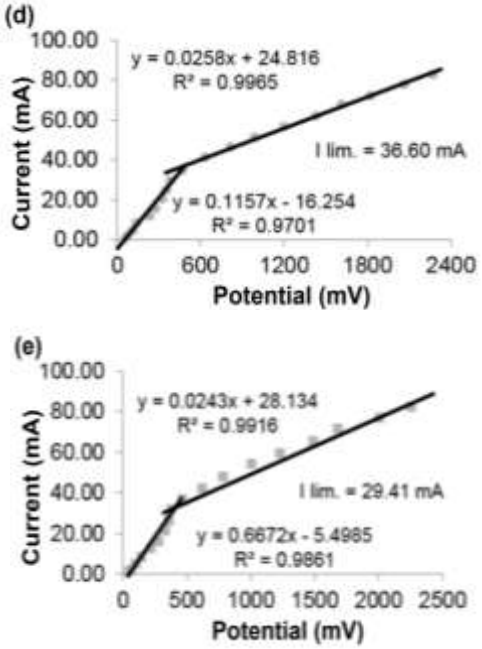



**Figure 5:** Triplicate CVC for the CEM shown in (a), (b) and (c) and for AEM shown in (d), (e) and (f), both at a volumetric feed flow of 200 mL.min$^{-1}$.



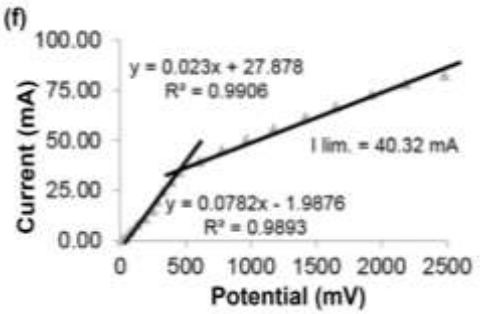
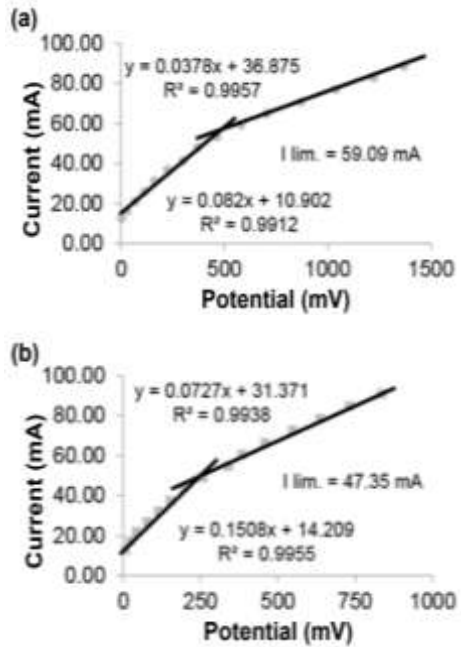




**Figure 6:**Triplicate CVC for the CEM shown in (a), (b) and (c) and for AEM shown in (d), (e) and (f), both at a volumetric feed flow of 400 mL.min$^{-1}$.



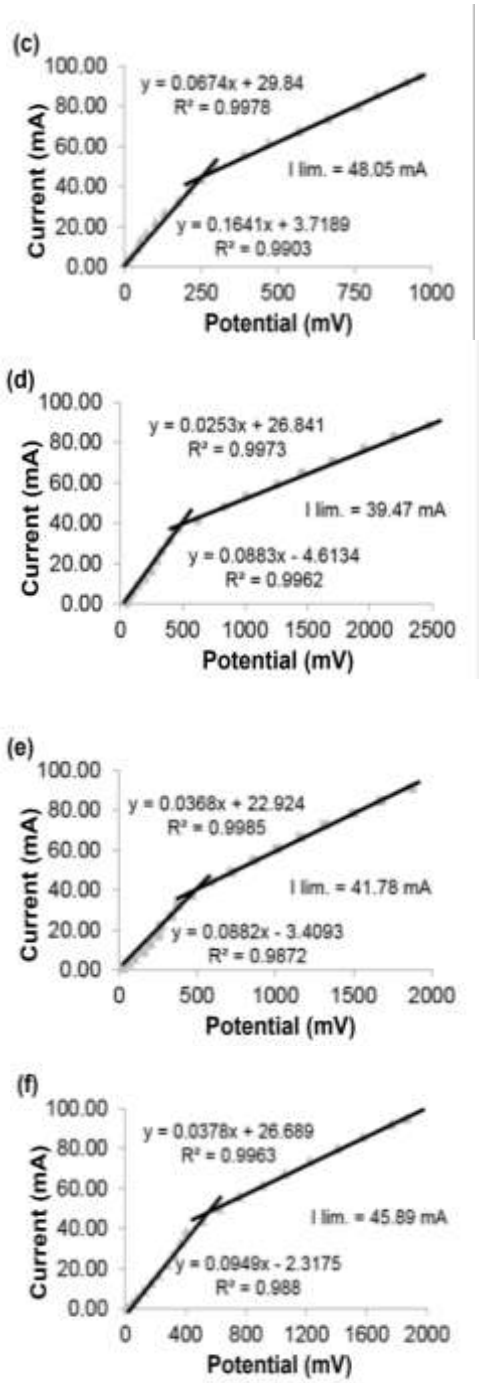



**Figure 7:**Triplicate CVC for the CEM shown in (a), (b) and (c) and for AEM shown in (d), (e) and (f), both at a volumetric feed flow of 600 mL.min$^{-1}$.

Table 2 shows the average values of the limiting current densities for CEM and AEM. The results indicate that the limiting current density is directly related to the volumetric feed flow. In addition, the limiting current density of the AEM is lower than the CEM, so it is the limiting membrane in the ED process.

**Table 2.**The limiting current densities for CEM and AEM at a NaCl concentration of 1000 mg.L$^{-1}$.

| Volumetric feed flow (mL.min$^{-1}$) | Limiting current density (mA.cm$^{-2}$) | |
|---|---|---|
| | CEM | AEM |
| 200 | 1.99 | 1.82 |
| 400 | 3.08 | 2.22 |
| 600 | 3.22 | 2.65 |

## IV. CONCLUSIONS

Our study showed that the limiting current density is directly related to the volumetric feed flow. The increase in the limiting current density occurs for both CEM and AEM. It is suggested to carry out works that deepen the behavior of the CEM and AEM at lower and higher volumetric feed flows.

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