VIETNAM JOURNAL OF HYDROMETEOROLOGY

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*Research Article*

# The research on electrodialysis model to treat brackish water in Ben Tre province

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Received: 13 November 2022; Accepted: 15 December 2022; Published: 25 December 2022

**Abstract:** Nowadays, clean water is becoming more scarce. People are getting closer to the adverse effects of climate change, especially the people of Ben Tre province those are heavily affected by seawater intrusion every year. The electrodialysis (ED) model, combined with electrostatic attraction and membrane filtration, has shown the ability to handle nearly 30% of salt concentrations of 5.5−7.9 g/L. The experiment also showed that air bubbles occur when the voltage of the model is increased higher than 26V. The model also promised a stable foundation to develop into a larger−scale model with more treatment stages and low electricity consumption. Moreover, it is possible to reuse the products produced by the ED model with two separate streams: a concentrated stream that can be applied to separate salts and a dilute stream that can be used as domestic water.

**Keywords:** Electrodialysis; Brackish water; Salinity treatment.

## 1. Introduction

The Earth is covered by 71% water, but only more than 1% can be drinkable and suitable for daily use [1–4]. In addition, the world is facing with the impact of climate change, including rising sea levels, drought, saline intrusion, and the saline boundary encroaching more profoundly into the mainland, causing severe consequences that directly affect people's lives [5–6].

The Mekong Delta has a geographical position in both directions bordering the sea, and is located in the lower Mekong River with a length of 4,800 km. The location makes the whole region a vulnerable area easily affected by the saline intrusion; many regions do not have clean drinking water. The river water in the dry season is increasingly salty, causing severe impacts on the lives and health of local people. In particular, the 2016 salinity drought caused 10% of people in Ben Tre province to have no clean water for daily activities. Domestic water in many areas still needs better quality [7]. Finding a reasonable and effective treatment method will significantly help improve the living condition of people in the Mekong Delta and Ben Tre province [8−9]. Therefore, an applicable process to desalinate the salty river water is essential. In addition, according to the report of Ben Tre province's official web portal, the salinity in their measurement points was a very high salinity for using, and the price of supplied water in dry season increased significantly. This leads to a need of indoor brackish water for this area.

Electrodialysis (ED), which is a combined process of DC application and ion exchange membranes [5−6], has been used for the desalination of brackish water and saline water. ED is designed by applying the filtering mechanism and electrostatic attraction [5, 10]. These mechanisms can reduce the number of salt ions in the water, purifying the water selectively by changing the parameters of voltage, amperage, and flow rate. ED has become a very effective technology in ion removal applied to many majors [11−12]. Thus, using ED to treat water in Ben Tre Province could be a promised technology.

According to [12] research on the history of the formation of electrodialysis technology, the basic principles of the technology were first discovered in the 1930s. In 1903, applied scientific articles The first ED technology released research on uncharged and non−polarized membranes.

The efficiency of ED is contributed by many factors such as voltage, temperature, flow rate, and feed concentration [1, 13−14]. In this study, an ED pilot module was designed to treat the Ben Tre River water in salt intrusion areas. In this study, the pilot model was implemented in the laboratory with voltage (at 20, 22, 24, 26, 28, and 30V) and feed concentrations were modified to determine the optimal voltage for a specific NaCl concentration range from 2 g/L to 20 g/L.

## 2. Materials and methods

### *2.1. ED setup*

The expected flow rate was 1 $m^3$/d, and the anion and cation exchange membranes are AMI−7001S and CMI−7000S, respectively. The research was implemented at a temperature of 25°C. The specifications of every element in this design are shown in Table 1.

**Table 1.** The specifications of every element in this design.

| Element | Function | Specifications |
|---|---|---|
| Ion exchange membrane | Allow only the corresponding ions to pass through the membrane to prevent the tank from reacting into dense flow compartments and clean water flow 2 types: cation and anion | Height × width: 14cm × 8.8 cm.<br>Total area/ type of membrane: 123.2 $cm^2$.<br>The no. of sheets: 6 sheets of each type.<br>The total useful area/of each type: 624 $cm^2$ |
| DC power supply | Power supply to the model | Voltage limitation: 0−30V<br>Current limitation: 0−10A<br>Power supply: up to 300W |
| Electrode | Create 2 electrode ends that draw opposite ions to two ends to support dense and dilute current separation. | Titanium mesh, D1.5 mm fiber as insoluble electrode |
| Working tank | Contain the electrodes, ion exchange membrane and | Mica Acrylics Taiwan<br>Thick: 15 mm<br>L×W×H = 20cm × 10cm × 15cm |
| Pump | Pump the feed water into the model. | Dosing membrane pump<br>0−45L/h |

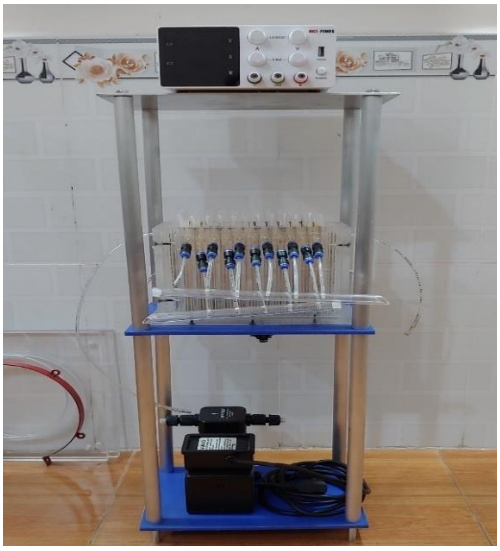

**Figure 1.** ED model.

*2.2. Cell and membrane*

In the first stage of designing, the model was arranged by layering up alternately Anion Exchange Membrane (AEM) and Anion Exchange Membrane (CEM) with a spacer between every pair. The spacers were made of mica, and the membrane was pasted on frames with silicon glue. Unfortunately, after dipping into the water, the membranes started to expand and come off the frames, leaving the water to flow freely between every stack. This condition also happened on applying the epoxy resin. Therefore, a new design was created to avoid this situation. The working tank was designed to contain 12 parallel separating trenches; every trench made room for a pair of one membrane and one spacer. The spacer was made to embrace the membrane and allow the membrane to stand without using glue; with this arrangement, the membrane could expand without leakage.

*2.3. Materials*

To find out the optimal voltage and other factors affecting the performance of the ED model, industrial sodium chloride produced by TRS was used in all experiments to produce feed water solutions with the concertation 2, 5, 8, 10, 15, and 20 g/L, namely. The applied voltage in treating every feed water concentration was changed at 20, 22, 24, 26, 28, and 30V.

*2.4. Analytical method*

The concentration of $Cl^-$ was analyzed by following TCVN 6194:1996. Each measurement was repeated three times, and calculate the average amount to have the results. The analysis was applied to both dilute and concentrated flow.

In this study, the removal efficiency was E, which was calculated as follows:

$$E\% = (C0 - C)/C0 \times 100 \quad (1)$$

where $C_0$ and C are feed and dilute concentrations, respectively.

## 3. Results and Discussion

*3.1. Optimal voltage*

The processing efficiency varies proportionally to the increase in voltage. With the same retention time and resistance, while increasing the voltage, the amperage also increased, affecting the current of the ions and thereby increasing the treatment efficiency; the same result could be observed in another research [1, 15].

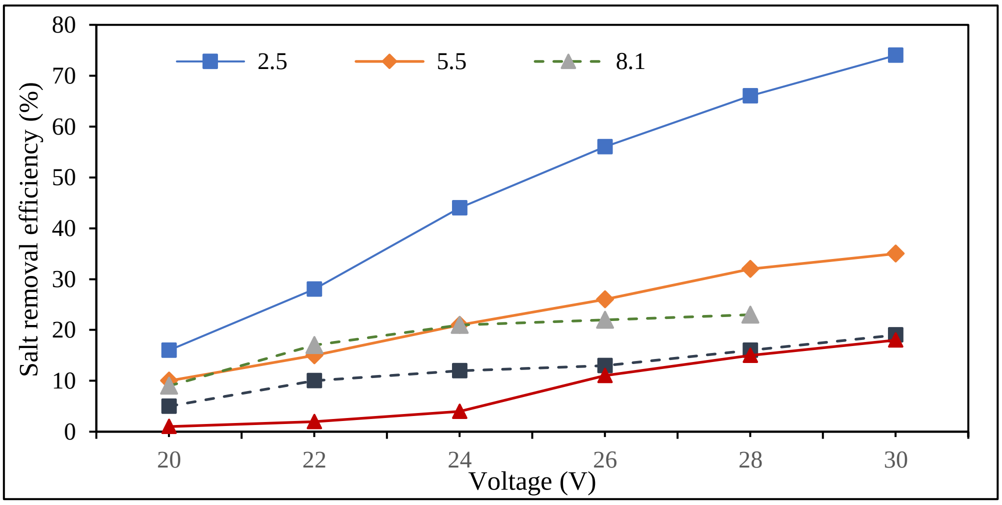


**Figure 2.** Processing performance at different voltages (20, 22, 24, 26, 28, and 30V) and feed brackish water concentrations (2.5, 5.5, 8.1, 10.1, 20 g/L).

After increasing the voltage to 28V, the two electrode compartments got bubble formation (Figure 3). The cause of this bubbling is the high voltage generated by the electrolysis of oxygen and hydrogen gas in water [16−17]. This phenomenon is partly due to the evaporation of Cl2 gas at the Anode [17], which is harmful to the model and the surrounding environment. To minimize this, the voltage should be kept at < 26V.

**Figure 3.** The bubbles formation in both electrode compartments.

In addition, on increasing the voltage, there was an upward trend in bubbles formation (which can contain Cl2) in the Anode compartment. The optimal voltage of 26V was considered a suitable application to river water; the efficiency at the 26V point tends to increase faster than the smaller voltages.

The efficiency of ED applying 26V for treating artificial salty water with concentrations 2, 5, 8, 10, 15, and 20 g/L was 56%, 26%, 21%, 13%, and 11%, respectively. It can be seen that the efficiency was not very high and decreased through the raising of NaCl concentration. This could be explained by the fact that with the flow rate of 1 $m^3$/day, the retention time is low, and the water velocity is too high for the ions to separate. The same result was observed by [15]. Therefore, to improve the performance of ED, the larger working tank and adding treatment stages could be applied [17−18]. Additionally, in the concentrate flow, the concentration increased by 37.5%, 22%, 22.86%, 28.87%, and 13.88% higher than the input with the concentrations 2, 5, 8, 10, 15, and 20 g/L. Thus, it is possible to produce raw salt by storing and drying this output flow [1].

According to above results, the voltage of 26V was the optimal voltage due to several reasons:

1. The removal efficiency of the higher voltage started to increase slower, which means that the higher voltage could not provide significantly higher efficiency. So, increasing the voltage could not improve the efficiency and also consume higher power.

2. From 28V, there was the bubble formation in Anode, this was Cl2 which not only toxic to the environment but also corrosive the model material.

Therefore, the efficiency could be improved by dividing the model into 2 parallel stages in order to increase the retention time.

Moreover, the ED models have a limited current density (LCD) [19], and the results of this experiment can give a correlation equation in the form of a logarithmic graph in which the increasing tendency of current density slowed down over the rising voltage (Figure 4). More specifically, the operation of the ED system should be kept lower than the LCD to ensure efficient use of amperage and no increase in resistance.

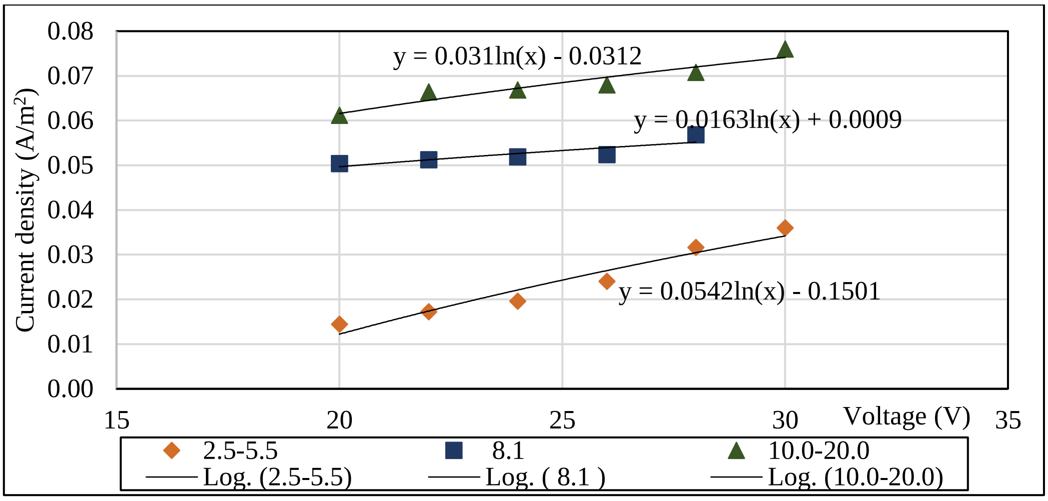


**Figure 4.** The current density changed over the rising voltage in 3 range of NaCl concentration (2.2−5.5, 8.1, and 10−20 g/L).

### *3.2. Optimal voltage*

In terms of cost efficiency, power consumption was calculated.

The formula for calculating energy consumption:

$$A = P \times t = (U \text{ x } I) \times t \quad (2)$$

where A is the power consumption (kWh); P is the electrical capacity (W); U is the potential difference (V); I is an amperage (A); t is the time (h) = 24h/day.

The power consumption of the experiment was deficient (Table 2).

**Table 2.** The power consumption in the experiment.

| Influent NaCl concentration (g/L) | Effluent NaCl concentration (g/L) | Voltage (V) | Energy (W) | Power consumption (kWh/ day) |
|---|---|---|---|---|
| 2.5 | 2.10 | 20 | 3.20 | 0.08 |
| 2.5 | 1.8 | 22 | 3.96 | 0.10 |
| 2.5 | 1.4 | 24 | 5.04 | 0.12 |
| 2.5 | 1.1 | 26 | 7.28 | 0.17 |
| 2.5 | 0.85 | 28 | 9.8 | 0.24 |
| 2.5 | 0.65 | 30 | 12.3 | 0.30 |
| 5.5 | 4.95 | 20 | 4 | 0.096 |
| 5.5 | 4.7 | 22 | 5.5 | 0.132 |
| 5.5 | 4.35 | 24 | 6.72 | 0.16128 |
| 5.5 | 4.05 | 26 | 8.32 | 0.19968 |
| 5.5 | 3.75 | 28 | 12.32 | 0.29568 |
| 5.5 | 3.55 | 30 | 14.7 | 0.3528 |
| 8.1 | 7.4 | 20 | 12.8 | 0.31 |
| 8.1 | 6.75 | 22 | 13.86 | 0.33 |
| 8.1 | 6.4 | 24 | 15.552 | 0.37 |
| 8.1 | 6.35 | 26 | 17.03 | 0.41 |
| 8.1 | 6.2 | 28 | 19.88 | 0.48 |
| 10.1 | 9.6 | 20 | 16.2 | 0.3888 |
| 10.1 | 9.1 | 22 | 16.5 | 0.444 |
| 10.1 | 8.89 | 24 | 19.44 | 0.46656 |
| 10.1 | 8.79 | 26 | 21.58 | 0.51792 |
| 10.1 | 8.5 | 28 | 24.36 | 0.58464 |
| 10.1 | 8.2 | 30 | 28.5 | 0.684 |
| 20.0 | 19.8 | 20 | 15.6 | 0.37 |
| 20.0 | 19.6 | 22 | 18.48 | 0.44 |
| 20.00 | 19.15 | 24 | 20.40 | 0.49 |
| 20.0 | 17.9 | 26 | 22.62 | 0.54 |
| 20.0 | 17.05 | 28 | 25.2 | 0.60 |
| 20.0 | 16.4 | 30 | 28.5 | 0.68 |

Figure 5 showed that the power consumption increased proportionally with feed water concentration, and the highest amount of the investigation was 0.68kWh/$m^3$ in applying 30V to treat the 20 g/L of NaCl in the input.

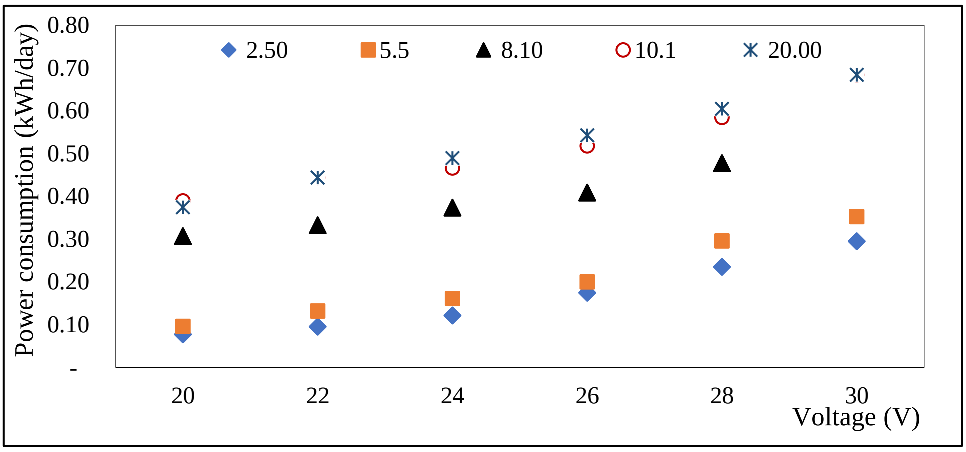


**Figure 5.** The power consumption trend.

For the voltage of 26V, the electrical capacity corresponding to the concentration of 2.5, 5.5, 8.1, 10, 20.1 µg/L respectively, is 0.175; 0.2; 0.409; 0.518; and 0.543 kWh/day, equivalent to 351.89−1,093.36 VND/m3/day (electricity price is 2,014VND/kWh−Ben Tre Power Company) compared to 9,600−9,900 VND/m3 in the rainy season and 27,846 − 35,581 VND/ $m^3$ in dry seasons and sometimes up to 150,000−200,000 VND/$m^3$ in drought period 2020−2021 (search on BEWACO website) when the water is treated by RO method provided by external parties. The model's application helps reduce 68−75% price compared to the water price in regular seasons, without high salinity concentration in water, and 91% compared to water supply in the salinity intrusion season. Compared with water prices, 42,000−51,500 VND/$m^3$ supplied by barge from the upstream, method can reduce by 94%. There is concrete proof of energy efficiency, but the cost depends strongly on the concentration of NaCl in the feed water [20]. However, counting the possibility of reusing the water in dilute and concentrated flow, this technology could serve as a chance to make a profit from producing raw salt and clean water.

## 4. Conclusions

The electrodialysis model can reduce down to 0.27 g/L salt concentration with low energy consumption and stable treatment performance. Although this treatment efficiency is enough to treat river water to meet QCVN 01−1:2018/BYT, more researches are needed to thoroughly treat the higher salt concentration and other pollutants in the river water. But this problem can be improved by increasing the retention time (increasing the membrane contact area or increasing the treatment steps).

The voltage of 26V was proved as the optimal voltage for the brackish water with the NaCl concentration ranging from 2g/L to have better efficiency (56%). For higher concentration, the voltage could be kept at 26V to avoid the formation of the bubble, especially Cl2.

The power consumption was very applicable whereas this technology does not cost much energy. In the voltage of 26V, the power consumption ranged only from 0.175 to 0.543 kWh/day and cost only 351.89−1,093.36 VND/$m^3$/day. By the results of very low power consumption, solar energy should be considered to combine with ED to create a more efficient treatment [21].

**Author contribution statement:** Constructing research idea: T.T.L., N.P.T.V.; Select research methods: T.T.L., N.P.T.V.; Take sample and sample analysis, data processing: N.P.T.V.; Writing original draft preparation: N.P.T.V.; Writing review and editing: T.T.L.

**Competing interest statement:** The authors declare that this article was the work of the authors, has not been published elsewhere, has not been copied from previous research; there was no conflict of interest within the author group.

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