Evaluation of the Electrodialysis Process in the Treatment of Phosphate Containing Solution

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1. Introduction

- Phosphorus (P) is an essential nutrient for all life forms;
- Demand of food and commodities industry $\rightarrow$ phosphate rock
  - One of the 20 critical raw materials$^1$;
- Excessive P loads inserted on natural water bodies:
  - Eutrophication$^2$;

1. Introduction

• Different processes were proposed to the recovery and concentration of P:
  – Biochar adsorption\(^2\);
  – Crystallization\(^3\);
  – Precipitation\(^4\) and;
  – Membrane-based process\(^5\)
    • Electrodialysis\(^6\);

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- The objective of this work was to test the technical feasibility of a 5-compartment ED cell in the treatment of a phosphate containing solution aiming the recovery of P from municipal wastewater;

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2. Materials and Methods

2.1. Solutions

- Phosphate containing solution:

<table>
<thead>
<tr>
<th>Salts</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaH$_2$PO$_4$·H$_2$O</td>
<td>0.33 g L$^{-1}$</td>
</tr>
<tr>
<td>Na$_2$HPO$_4$·7H$_2$O</td>
<td>0.65 g L$^{-1}$</td>
</tr>
</tbody>
</table>

- Electrolytic solution:

<table>
<thead>
<tr>
<th>Salt</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na$_2$SO$_4$</td>
<td>4 g L$^{-1}$</td>
</tr>
</tbody>
</table>
2. Materials and Methods

2.2. Electrodialysis Cell

- Membranes:
  - CEM: HDX100;
  - AEM: HDX200;
  - Supplied by Hidrodex®;
  - 16 cm²;

- Electrodes:
  - Ti/70TiO₂30RuO₂;
  - 16 cm²
2. Materials and Methods

2.3. Determination of the limiting current density

- Current-Voltage Curves (CVC) method\textsuperscript{9};
- 2 mA each 30 seconds;
- Duplicate.

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2.4. Electrodialysis experiments

- ED tests were carried out in triplicate;
- Room temperature;
- Conductivity, pH and cell potential were monitored;
- Solution aliquots were collected at pre-established time and submitted to ion chromatography analysis;
  - Study of the ions transfer;
  - Efficiency of the ED process to remove and recover phosphate;

\[
pe\% = \frac{(C_i - C_t)}{C_i} \times 100
\]
3. Results and Discussions

3.1. Limiting current density

- HDX100:
  - one plateau
  - one $i_{\text{lim}}$
  - typical behavior\textsuperscript{10};

\begin{itemize}
\end{itemize}
3. Results and Discussions

3.1. Limiting current density

- **HDX100:**
  - one plateau
  - one $i_{lim}$
  - typical behavior$^{10}$;

- **HDX200:**
  - two plateaus
  - two $i_{lim}$
  - differs from the conventional;

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3. Results and Discussions

3.1. Limiting current density

Presence of two plateaus\textsuperscript{11}

Different phosphorus-containing species\textsuperscript{12}

pH conditions

3. Results and Discussions

3.2. Evaluation of Electrodialysis

- 0.53 mA cm$^{-2}$;
  - 75% of $i_{\text{lim,AEM}}^{13}$;
- 15 hours;
  - 200 µS cm$^{-1}$ (water supply);

3. Results and Discussions

3.2. Evaluation of Electrodialysis

- Conductivity

![Electrodialysis Diagram]

**Graph:**
- Conductivity (mS cm⁻¹) vs. Time (h)
- Concentrated anode
- Diluted
- Concentrated cathode
- Electrodes
3. Results and Discussions

3.2. Evaluation of Electrodialysis

- pH

Water Dissociation

<table>
<thead>
<tr>
<th>OH⁻</th>
<th>H⁺</th>
</tr>
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</table>

Pass through the AEM

Shifts the equilibrium to the formation of $\text{H}_3\text{PO}_4$

pH in the diluted compartment

![Graph showing pH over time with different compartments and electrodes]
3. Results and Discussions

3.2. Evaluation of Electrodialysis

- Cell voltage

- Removal of the number of ions available in D compartment
- Solution electrical resistance increases
- pH of central compartment decreases
- Formation of $H_3PO_4$
3. Results and Discussions

3.2. Evaluation of Electrodialysis

<table>
<thead>
<tr>
<th>Ionic specie</th>
<th>Percent Extraction (pe%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phosphate-containing species</td>
<td>(60.82 ± 6.48) %</td>
</tr>
<tr>
<td>( \text{H}_x\text{PO}_4^{x-3} )</td>
<td></td>
</tr>
<tr>
<td>Sodium (( \text{Na}^+ ))</td>
<td>(92.21 ± 1.21) %</td>
</tr>
</tbody>
</table>

- While the pe\% for \( \text{Na}^+ \) is over than 92\%, phosphate-containing species reported a lower value, around 61\%, possibly due to \( \text{H}_3\text{PO}_4 \) availability;
4. Conclusions

- CVCs showed an unusual behavior for the AEM (HDX200);

  - Changes on pH conditions in D compartment
  - Formation of $\text{H}_3\text{PO}_4$
  - pe% of P-containing species was restricted

- Further experiments should be done to try to achieve higher phosphate species recovery;
  - Controlling the solution pH;
  - operating in a continuous way or;
  - changing successively the solution in the diluted compartment.
Acknowledgements