Conversion of Sodium Lactate to Lactic acid and Sodium Hydroxide with Cation Exchange Membrane Electrolytic Cell

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Abstract. This research conversion of sodium lactate to lactic acid and sodium hydroxide with electrolysis technique combined with cation exchange membrane (CEM). The electrolytic cell has effective membrane area of 144 cm². Experiments were carried out by feeding sodium lactate solution which was prepared with alkaline degradation of invert sugar. This solution was feed through the anolyte. The process was studied in terms of the initial concentration of sodium lactate (i.e. 0.75, 1.20 and 1.50 M) and the applied voltage (i.e. 4, 6 and 8 volt) to assess the efficiency of separation. The results suggested that the transport of sodium ion through the membrane was proportional to the applied voltage but it was not depend on sodium lactate concentration which was used as feed. The current efficiency increased as the applied voltage increased. Conversely, the energy consumption with respect to sodium hydroxide production increased with both factors. From this experiment, it was found that the highest lactic acid recovery was 55.5% at 4 volt and initial lactate concentration of 0.75 M.

1. Introduction

Polylactic acid is a bioplastic which produced from polymerization of lactic acid (CH₃CHOHCOOH). Lactic acid is organic acid which composed of carboxyl group and hydroxyl group. Lactic acid can be produced from renewable resource) such as corn, cassava. Lactic acid can be produced from fermentation or chemical synthesis. In present, the most lactic acid was produced with fermentation because it got high yield of lactic acid more than 90% depended on raw material, the type of microorganism or the method of fermentation. [1]. However, the fermentation is difficult to control microorganism and used long fermentation time. Lactic acid from chemical synthesis got lower yield than fermentation, but it was simple and not take long time of reaction. Alkaline degradation, a chemical synthesis, it is reaction between monosaccharide, di-saccharide or polysaccharide with alkaline. The most used alkali was sodium hydroxide (NaOH), potassium hydroxide (KOH), calcium hydroxide (Ca(OH)₂) [2, 3]. The main product was lactate salts, which could be convert to lactic acid, the other products were the salt of saccharinic acid (>C₆) and higher molecular weight compound [2].

Many techniques were proposed to convert lactate salt to lactic acid, such as adsorption [4], reactive distillation [5] or electrodialysis [6,7]. The adsorption process requires regenerated of ion-exchange resin and use more chemicals. Reactive distillation required high energy consumption and necessary large amount of chemicals. Electrodialysis is an attractive because this process didn’t generate waste, and no cost for waste disposal.
This research study on conversion of sodium lactate, from alkaline degradation of invert sugar and sodium hydroxide, to lactic acid with electrodialysis and cation exchange membrane. Moreover, alkali which didn’t react occurred can recycled to alkaline degradation. It will decreased the production cost.

2. Material and Methods

2.1. Material and Electrodialysis Equipment

2.1.1. Material: Sodium lactate was synthesized in our laboratory. Sodium hydroxide (NaOH) and sulfuric acid (H₂SO₄) were analytical grade.

2.1.2. Electrodialysis Equipment: The single stage in-house electrodialysis unit consisted of cation exchange membrane (Selenium CSO, AGC Engineering Ltd., Japan). The effective membrane area was 144 cm² and located between anolyte and catholyte compartment. The two electrodes made from stainless steel 304. The schematic diagram was shown in Figure 1.

![Schematic diagram for electrolysis. C is cation exchange membrane](image)

**Figure 1.** Schematic diagram for electrolysis. C is cation exchange membrane

2.2. Method

Sodium lactate was added with CO₂ until pH about 8-9. The solution was filtered and the filtrated was use for electrodialysis.

2.2.1. Factors effect on electrodialysis:

Sodium lactate and 0.001N sodium hydroxide (NaOH) at flow rate 0.3 ml/s were circulated though anode and cathode side, respectively. The samples from anode side and cathode side were taken periodically for analyze the concentration of lactic acid and NaOH, respectively. The effect of initial concentration of sodium lactate varied at 0.75, 1.2 and 1.5 mol/L. The voltage was supplied and varied at 4, 6 and 8 V. The current during run were recorded for calculate current efficiency and energy consumption as shown in eq.(1) and (2), respectively.

\[
CE (\%) = \frac{96.485 N_{NaOH}}{Q} \times 100 \tag{1}
\]

\[
W = \int_{0}^{t} \frac{V I}{N_{NaOH}} \, dt \tag{2}
\]

Where

- \( CE \) = current efficiency (%)
- \( W \) = energy consumption (kWh/kg NaOH)
- \( N_{NaOH} \) = mol of NaOH in cathode side (mol)
- \( Q \) = electrical (coulomb)
- \( V \) = voltage (volt)
- \( A \) = current (amp)
- \( t \) = time (hr.)
2.2.2 Analytical Procedure:

Samples were taken for analyze the lactic acid concentration with High performance liquid chromatography (HPLC). The column was Plastisil ODS column and the detector was UV at 210 nm. The 5 mmol sulfuric acid was mobile phase at flow rate of 0.8 ml/min.

The samples were analyze the concentration of NaOH with titration with 0.01 mol/L of hydrochloric acid.

3. Result and Discussions

3.1. Effect of initial concentration of sodium lactate

The sodium lactate solution was feed to anode side at constant voltage. The sodium ion (Na⁺) will transport though cation exchange membrane to cathode side and form NaOH in cathode side. While lactate ion (CH₃CHOHCOO⁻) moved to anode and form lactic acid in anode side. The reaction at anode and cathode showed in eq. (3) and (4), respectively.

At Anode:

\[ \text{H}_2\text{O} \rightarrow 2\text{H}^+ + \frac{1}{2} \text{O}_2 + 2e^- \quad E^0 = +1.229 \text{ V} \quad \text{(3)} \]

At Cathode:

\[ 2\text{H}_2\text{O} + 2e^- \rightarrow 2\text{OH}^- + \text{H}_2 \quad E^0 = -0.828 \text{ V} \quad \text{(4)} \]

From the experiment, the O₂ and H₂ was found at anode and cathode, this phenomenon was explained in eq.(3) and eq.(4)

The effect of initial concentration of sodium lactate was study at varied time as shown in Figure 2. The concentration of NaOH increased when time increased. It showed that Na⁺ can pass though cation exchange membrane. When the initial concentration of NaOH varied from 0.75, 1.2 and 1.5 mol/L, it got NaOH as 0.7, 0.9 and 1 mol/L, respectively.

Considering the initial concentration of sodium lactate showed that concentration had no significant impact on the NaOH which was produced at cathode side. This results was similar to Simon et.al [8] found that the transport of Na⁺ through the membrane didn’t vary when using different brine concentration.

Figure 2. The concentration of NaOH at cathode side at constant 8 volts.

Figure 3. The current efficiency and energy consumption at 0.75, 1.2 and 1.5 M of sodium lactate.
The depletion of Na\(^+\) occurred at anode side and increase at cathode side. The increasing of Na\(^+\) at cathode side was used to calculate current efficiency. The current efficiency and energy consumption as a function of using varied concentration of sodium lactate as shown in Figure 3. The current efficiency decreased, when concentration of sodium lactate increased.

When high concentration of sodium lactate was used, there are more Na\(^+\) in anode side but the transfer of Na\(^+\) wasn’t depend on concentration of sodium lactate, see Figure 2. Furthermore, it used long time in transfer, so the current efficiency decreased and energy consumption increased. Moreover, the current lose due to the resistance of electrode, membrane and solution in both sides.

The percentage of recovery lactic acid decrease with different concentration of sodium lactate as shown in Figure 4. The highest recovery lactic acid was 48% at initial concentration of 0.75 mol/L and 8 volts.

![Figure 4](image_url). The recovery of lactic acid from sodium lactate at constant voltage at 8 Volts.

### 3.2. Effect of voltage

The rate of production NaOH in cathode side increased according to voltage as shown in Figure. 5. From the result, the voltage will improve Na\(^+\) transfer. The current efficiency and energy consumption increased as voltage was increased as shown in Figure.6. At low voltage, the rate of H\(^+\) or OH\(^-\) which was produced was low. On the other hand, the rate of H\(^+\) or OH\(^-\) will increase at high voltage. However, energy consumption has recession trend because the more gas production (formed bubble) at high voltage, it reduced the area of electrode and the effective membrane area [9]. Moreover, the bubble will decrease conductivity of electrolyte [10].

![Figure 5](image_url). The concentration of NaOH at cathode side at constant 4, 6 and 8 volts.

![Figure 6](image_url). The current efficiency and energy consumption at 0.75 M of sodium lactate at 4, 6 and 8 volts.
When the voltage was increased, the lactic acid was decrease as shown in Figure 7. The highest recovery of lactic acid was 55.5\% at 4 V. At high voltage lactate ion might be oxidized to pyruvate ion and proton as shown in eq.(5), so lactic acid decreased. Moreover the produced sodium hydroxide increase at higher voltage, sodium hydroxide was produced 0.23, 0.57 and 0.73 M from 0.75 M of sodium lactate at 4, 6 and 8 V, respectively.

\[
\text{lactate} \rightarrow \text{pyruvate} + 2\text{H}^+ + 2\text{e}^- \quad (5)
\]

In previous research, the lactic acid was recovered with electrodialysis and anion exchange membrane, the recovery of lactic acid was about 70-80\% from sodium lactate which was prepared with titrated lactic acid with NaOH, while the recovery was 78\% from fermentation broth [7]. Moreover, the other research used in-house electrodialysis with cation and anion exchange membrane to recovery lactic acid from fermentation broth, the highest recovery of lactic acid was 92\% with 100\% the purity at optimal condition [11].

Although, the results from this research may be got lower the percentage of recovery of lactic acid than previous research due to this research used cation exchange membrane which may more suitable to recovered sodium hydroxide than lactic acid. However, it could recovered 49\% lactic acid and got high quality of NaOH about 0.73 mol/L from 0.75 mol/L of sodium lactate and applied voltage at 4 volts.

![Figure 7. The recovery of lactic acid from sodium lactate at constant voltage at 4, 6 and 8 Volts.](image)

**Figure 7.** The recovery of lactic acid from sodium lactate at constant voltage at 4, 6 and 8 Volts.

4. **Conclusions**
The initial concentration of sodium lactate didn‘t influence on the rate of transfer Na\(^+\), conversely the voltage has effected on the rate of transfer of Na\(^+\).

When initial concentration of sodium lactate was increased, the energy consumption increased but the current efficiency decreased. While the voltage increased, the energy consumption and the current efficiency increased.

This process is feasibility alternative for conversion lactic acid from sodium lactate which was synthesis with chemical reaction. The lactic acid can be recovered 50\%, furthermore it can produced NaOH which can recycle for alkaline degradation, and decrease cost of production.

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