Treatment of wastewater from alumina plant by electrodialysis

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Abstract. The alumina plant emits a large amount of production wastewater every day, which causes serious pollution to the environment and also seriously wastes water resources. In response to this problem, the electrodialysis method was used to treat and recycle the wastewater from the alumina plant. The test adopts cyclic desalination. The volume of fresh water controlled during the test is 4 times of the volume of concentrated water, that is, the recovery rate of wastewater is 80%. The constant pressure, constant current operation and the desalination effect of fresh water inlet line speed under constant pressure conditions are respectively carried out. the optimal operating conditions of the system was determined.

Using 100 V terminal voltage to control fresh water and concentrated water inlet line speed of 5 cm / s, three parallel desalination tests were carried out. The results showed that the salt content of fresh water was less than 500 mg /L. and the water quality meets the industrial water requirements of the alumina plant. The energy consumption per unit of water production is relatively low, less than 1.75 kw·h /m³ fresh water, which is beneficial for economic development.

1. Introduction

The alumina plant production process requires a large amount of water and also produces a lot of wastewater. Domestic large-scale alumina plant can discharge 4~60,000 m³ of wastewater per day. There are five large-scale alumina plants in domestic with a total discharge capacity of 300,000 m³ per day. This type of wastewater is mainly derived from alkali-containing waste liquid at the alumina production site, production line of production water and other subsidiary units of the water and factory-owned thermal power plants water [1]. Except a small part of the wastewater can be reused after sedimentation treatment, the rest is neutralized by acid and discharged directly. This treatment not only seriously wasted water resources, but also caused serious pollution to the surrounding river ecology and agricultural production.

In response to the above problems, each alumina plant has carried out a zero-discharge project for production wastewater research [2 - 5], and established some wastewater treatment projects. These projects recycle water and the source is mainly treated by adding FeSO₄, T-1150 and other flocculant to treat wastewater. The chemical composition of treated wastewater has not changed except for the decrease of suspended matter and turbidity [6]. The Recycled water has high salinity and alkalinity. Poor water quality limits the scope of recycling, and most of the treated water is difficult to use and still discharged. To further expand the use range of wastewater and improve the water quality of reclaimed water, it is necessary to carry out deep purification treatment.

In this paper, the electrodialysis technology is used to treat the wastewater from the alumina plant...
depth. Electrodialysis treatment of alumina wastewater has advanced technology and high economic benefit, the wastewater has a low salt content and can reach the water standard of the alumina plant.

2. Experiment

2.1 Experiment device
Electrodialysis device adopts stainless steel plate electrode, 3361 positive film and 3362 negative film, the effective area of single film is 175 mm x 350 mm, the partition thickness is 0.8 mm, the electrodialysis device is equipped with 20 pairs of film. There is a shunt for measuring the current on the circuit and a pair of platinum plates for measuring the voltage of the film reactor is inserted at both ends of the film reactor. The volume of the concentrated tank and the extreme tank is 500 L respectively, and the volume of the fresh water tank is 1,000 L.

2.2 Water quality analysis
Raw water is industrial effluent wastewater from an alumina plant. The water quality analysis is shown in Table 1.

| element | Na | Ca | Mg | Fe | K | Al | Si | Cl | SO$_4$^2- | HCO$_3$^- | CO$_3$^2- | F |
|---------|----|----|----|----|---|----|----|----|--------|---------|---------|----|
| content/ (mg*L$^{-1}$) | 365 | 12 | 15 | 0 | 29 | 1.319 | 323.2 | 305.2 | 262.3 | 105.3 | 0.5 | 1180
| measured data | 323 | 262 | 105 | 0.5 | 1180 |
| calculated value | 305 | 295 | 105 | 0.5 | 1180 |

Because sodium is the main component of this industrial wastewater, Sodium content can be used as an indicator of desalination during the desalination process.

2.3 Experiment methods
Using cyclic desalination, concentrated water, fresh water, and polar water are independently cycled, use a rotameter to measure the flow. Control the volume of fresh water is 4 times the volume of concentrated water, that is, the yield of fresh water is 80%, the Na$^+$ content in concentrated and fresh water was sampled at the outlet.

2.4 Analytical methods
Determination of the content of each metal element by atomic absorption method; F content by ion selective electrode method; Cl content by silver nitrate titration; SO$_4$^2- content by turbidity method; CO$_3$^2-, HCO$_3$- content by titration method; The pH value was measured.

2.5 Data processing
Desalination rate $Y$ is calculated as follows:

$$ Y = \frac{C_{di} - C_{do}}{C_{di}} \times 100\% $$

$C_{di}$ is the original water salt concentration, mg / L; $C_{do}$ is the freshwater production water salt concentration, mg/L. The formula for calculating the DC power consumption $H$ per unit freshwater production is as follows:

$$ H = \frac{IVt}{W} $$

$I$ is the current intensity, A; $V$ is the stack voltage, V; $t$ is the desalting time, s; $W$ is freshwater production, m$^3$.

3. Experiment results and discussion

3.1 Constant voltage desalting experiment
The operation of electrodialysis is generally carried out under the limit current density, and the empirical formula for the limit current density of this system is as follows:

$$ I_{lim} = 0.0116 \times C_{di}^{0.974} \times V^{0.717} $$

$C_{di}$ = 1 343. 86 mg/L, the degree is 39. 43 A / m$^2$ when the limit current density at line speed of
5cm/s. The effective area of the electrodialyzer used in this experiment is 0.061m\(^2\), so the ultimate current strength is 2.42 A.

![Figure 1. Influence of operating voltage on desalination](image)

It can be seen from figure 1 that the desalination rate increases with the increase of desalting time, but the effect of desalting under different voltages is different in the same period of time. The optimum desalination voltage of this system is 100 V.

![Figure 2. Correlation of energy consumption and Na\(^+\) concentration of freshwater on different voltage](image)

The DC power consumption per unit of electrodialysis unit is plotted against the Na\(^+\) content of fresh water. It can be seen from the figure 2 that as the amount of Na\(^+\) in fresh water decreases, the conductive ions in fresh water continue to decrease, the electrical resistance increases, and the energy consumption of the membrane stack increases continuously. That is, the DC power consumption per unit of water production increases.

3.2 Effect of different current intensity on desalination

In order to compare the desalting effect under different operating conditions, the optimal desalting conditions were determined, and the desalting tests under different current intensities of 3 A, 4 A, 5 A and 6 A were conducted.
Figure 3. Influence of current intensity on desalination

Figure 3 shows the effect of current intensity on desalination rate. As can be seen from the figure, the desalting rate increases linearly with the increase of desalting time. Since the current intensity is a parameter representing the speed of the desalting process, the higher the current intensity is, the higher the desalting rate will be in the same desalting time.

Figure 4. Correlation of energy consumption and Na\(^+\) concentration of freshwater on different current intensity

Figure 4 shows the Na\(^+\) energy consumption of fresh water at different current intensities. As can be seen from the figure 4, with the decrease of salt content (represented by Na\(^+\) content) in fresh water, the conductivity of fresh water decreases and the energy consumption of desalination per unit of fresh water increases continuously. Moreover, when the Na\(^+\) content in fresh water is about 200 mg/L, the increase amplitude suddenly increases. However, the slope of the curve is different under different current intensities. The curve with higher current intensity has a higher slope. This indicates that desalination under high current intensity will increase energy consumption and unit fresh water production cost.
3.3 Water linear velocity effect on desalting effect of electrodialysis desalination process
Especially under the limiting current density of desalination, desalination rate can have nothing to do with the concentration of raw water, it’s just a function of the linear velocity of fresh water and can be said as follows [8]

\[ B_{lim} = A e^{-Vg} \]  

(4)

The A and V for fixed assembly electrodialyzer is constant indicator, which can be obtained from experiments. It can be seen from the above equation that the desalination rate under the limit current density is inversely proportional to the fresh water inlet speed, but the desalination rate under the non-limit current density does not necessarily comply with the above law.

![Figure 5](image)

Figure 5  Correlation of desalination and linear velocity of freshwater
Figure 5 shows the desalination rate curves at different linear velocities of fresh water under the voltage of 100v. It can be seen that light water linear velocity is 4 cm/s, 5 cm/s desalination rate was close to the trend line. The results show that there is little difference in desalting effect between the two kinds of fresh water. However, the curve of fresh water inlet linear velocity of 3 cm/s is above the curve of 4 cm/s and 5 cm/s, which indicates that when the linear velocity of fresh water inlet is 3cm/s, higher desalination rate can be obtained. This result basically accords with the conclusion of formula 4.

3.4 Repeated experiment results
According to the above experiment, three parallel desalination experiments were conducted under the condition that the terminal voltage was 100 V, the velocity of fresh water and concentrated water line was controlled to be 5 cm/s, so as to conduct the repeatability of the experiment results. Chemical analysis was carried out on the fresh water mixture samples of repeated experiments, Ca²⁺, Mg²⁺ and CO₃²⁻ were basically removed after desalination, and these waters were recycled and utilized to remove potential safety hazards for the alumina plant.

4. Conclusion
The following conclusions can be drawn from the condition experiment and the repeatability experiment under better conditions.

1) Under the limit current density, the constant pressure electrodialysis operation was carried out, and the optimal operating voltage of the system was determined to be 100V, at which time the desalting effect was the best and the energy consumption was low.

2) Constant current electrodialysis desalting, high current density, fast desalting speed and high
desalting rate; However, when the current density is high, the energy consumption of desalination will increase, that is, the production cost will increase. Therefore, the actual operation should be carried out under the condition of lower than the limit current density.

3) In the case of limiting current density, desalination rate is inversely proportional to the linear velocity of fresh water inflow. However, there is no inverse law of desalination rate in the case of non-limiting current density. In actual production, the operation under the limit current density, should not use too high fresh water inlet speed.

4) The repeatability experiment showed that the electrodialysis process was used to treat the effluent discharged from the alumina plant, and the experiment repeatability was good. The salt content of fresh water produced was less than 500mg/L, and the energy consumption per unit of water production was less than 1.75kw·h/m³ fresh water, which had good economic benefits, Fresh water quality meets the general industrial water quality requirements of alumina plants.

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