Effect of Working Solution Parameters on the Performance of Reverse Electrodialysis Stack and Cr(VI) Reduction Rate

Rong Fu*, Lei Jiang

College of Energy Storage Technology, Shandong University of Science and Technology, Qingdao, China

*fr17860260791@163.com

Abstract. In this paper, a method of treating water polluted by persistent pollutants by salinity gradient and generating electricity at the same time is proposed. In fact, a solution of different salinity gradients creates a potential difference between the electrodes, which generates electrical energy by utilizing suitable electrolytes and external circuits. By using the salinity gradient and the REDOX process, the reverse electrodialysis treatment of Cr(VI) wastewater and power generation have been successfully achieved. In this paper, the control variable method is used to investigate the influence of different operating conditions on the reactor performance and Cr (VI) reduction rate. The effects of different concentration gradients, different solution flows and different solution temperatures on the output voltage, internal resistance and maximum power density of the reactor and the Cr (VI) reduction rate were tested. The results show that the salinity gradient and flow rate of the working solution have great influence on the degradation of Cr(VI), while the temperature has little influence on the degradation of Cr(VI).

Keywords: Reverse electrodialysis, Cr(VI) degradation, Salinity gradient energy

1 Introduction

The efficient development and utilization of salt differential energy can effectively alleviate the dependence on traditional energy sources and help achieve the national goal of double carbon[1]. Reverse electrodialysis (RED) is an effective technical means to recover salt differential energy and directly convert it into electric energy[2, 3].However, due to low power density, low conversion rate and high cost, it is difficult to achieve large-scale application at present[4, 5]. On the other hand, highly toxic Hexavalent chromium, Cr(VI) discharged from industrial and agricultural production will cause heavy metal pollution in groundwater and soil, which will threaten human health through the enrichment of food chain[6, 7]. Reducing hexavalent chromium with high toxicity to trivalent chromium with low toxicity is a technical route to treat wastewater

W. He et al. (eds.), *Proceedings of the 2024 10th International Conference on Advances in Energy Resources and Environment Engineering (ICAESEE 2024)*, Atlantis Highlights in Engineering 36,
https://doi.org/10.2991/978-94-6463-708-3_49

containing chromium at present. However, the traditional reduction method has some problems such as high cost, high energy consumption and easy secondary pollution[8].

Therefore, combining with the working characteristics of reverse electrodialysis stack, we propose to use wastewater containing hexavalent chromium to replace the traditional electrode washing solution in the cathode electrode chamber. By generating potential difference between different salt concentrations and using appropriate electrolytes and external circuits, we can achieve the dual goals of generating electricity by using salt difference energy and degrading hexavalent chromium in wastewater. In this paper, the effects of salinity gradient, flow rate and temperature on degradation and reactor performance were investigated.

2 Experiment

The RED reactor is the core device of the system to degrade hexavalent chromium. Electrochemical workstation and current amplifier are connected in series to test the performance of RED reactor. Peristaltic pump for feed solution and peristaltic pump for electrode solution are used to provide flow power and control flow rate; Thermostatic water tank is used to ensure that the feed solution is maintained at a constant temperature; Ultra-pure water purifier, electronic balance and magnetic stirrer are used for the configuration of electrode flushing liquid. In this experiment, the control variable method was adopted, and only one variable principle was adopted for each group. The salinity gradient, flow rate and temperature of the working solution were changed respectively. At the end of each experiment, the RED reactor was flushed with deionized water. The concentration of Cr(VI) was determined by ultraviolet spectrophotometer. During the experiment, each group of experiments repeated the test three times, and the mean value and standard deviation of the three test data were used to analyze the experimental error.

3 Results and Discussion

3.1 Effect of Concentration Gradient on Performance of RED Stack and Reduction of Cr(VI)

Fig. 1 shows the effects of different concentration gradients (3 mol/L-0.03 mol/L, 3 mol/L-0.6 mol/L, 3 mol/L-0.06 mol/L) on the reduction rate of Cr(VI), and the variation of the output performance of the stack with time. Fig. 1(a) shows the power density under different concentration gradients. When the concentration gradient is 3 mol/L-0.03 mol/L, it reaches the short-circuit maximum power density, and when the concentration gradient is 3 mol/L-0.6 mol/L, it reaches the short-circuit minimum power density, with a difference of 0.293 W/m^2.

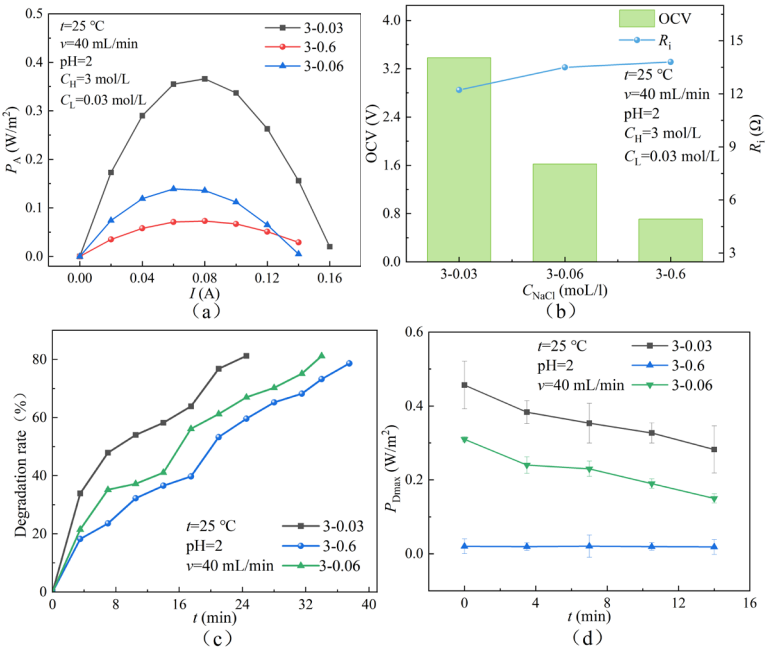

Fig. 1. Variation diagram of Cr(VI) reduction rate and RED stack performance under different concentration gradients.

Fig. 1(b) shows the OCV and internal resistance under different concentration gradients. It can be seen that the maximum OCV is 3.38 V when the concentration gradient is 3 mol/L-0.03 mol/L, and the minimum value is 0.71 V when the concentration gradient is 3 mol/L-0.6 mol/L.Figure 1(c) shows the reduction rates of different concentration gradients. It can be seen that the reduction rate increases with the increase of concentration gradient, and the reduction rate can reach 80% within 40 min. Fig. 1 (d) show the variation law of total power density and voltage of the loop with time. With the increase of concentration gradient, both power density and voltage show an increasing trend. According to Gibbs free energy formula, increasing the concentration gradient between solutions can increase Gibbs free energy between solutions. Therefore, with the increase of concentration gradient, its OCV and power density also increase. According to Nernst equation, when the initial concentration of Cr(VI) is unchanged, the required reduction potential remains unchanged. Therefore, the reduction rate of Cr(VI) increases with the increase of concentration gradient.

3.2 Effects of flow Rate and Temperature on Performance of RED Stack and Cr(VI) Reduction Rate

Fig. 2 shows the effects of different working solution flow rates (30 mL/min, 40 mL/min, 50 mL/min, 70 mL/min and 90 mL/min) on the reduction rate of Cr(VI), and the variation of the output performance of the stack with time. Fig. 2(a) shows the

power density at different working solution flow rates. When the working solution flow rate is 90 mL/min, the short-circuit maximum power density is 0.55 W/m^2, and when the electrode liquid flow rate is 30 mL/min, the short-circuit minimum power density is 0.27 W/m^2, with a difference of 0.28 W/m^2.

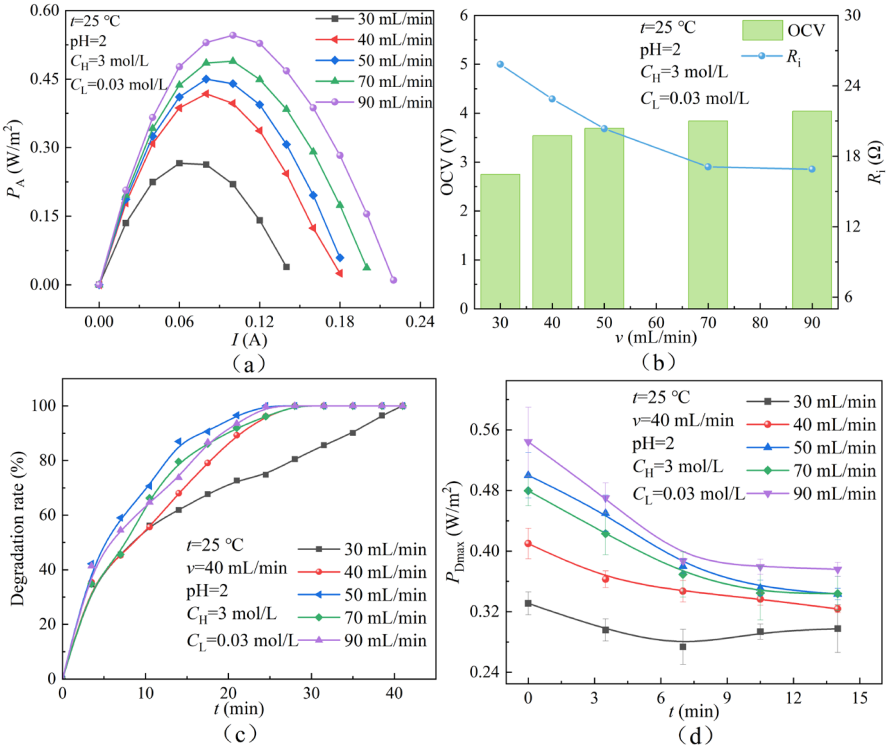

Fig. 2. Variation of Cr(VI) reduction rate and performance of RED stack at different working solution flow rates.

Fig. 2(b) shows the OCV and internal resistance at different working solution flow rates. It can be seen that the OCV is the maximum of 4.04 V when the electrode liquid flow rate is 90 mL/min, and the minimum of 2.75 V when the electrode liquid flow rate is 30 mL/min, with a difference of 1.29 V. Fig. 2(c) shows the reduction rate of different working solution flow rates. It can be seen that the reduction rate of Cr(VI) increases at first and then decreases with the increase of working solution flow rate, and the reduction is basically completed within 40 min. Fig. 2 (d) reflect the law of the total power density and voltage of the loop changing with time. With the increase of the working solution flow rate, both power density and voltage show an increasing trend. In the process of increasing the flow rate, the increase of the number of transmembrane ions per unit time leads to the increase of current density and voltage, which better reaches the reduction electromotive force of Cr(VI).

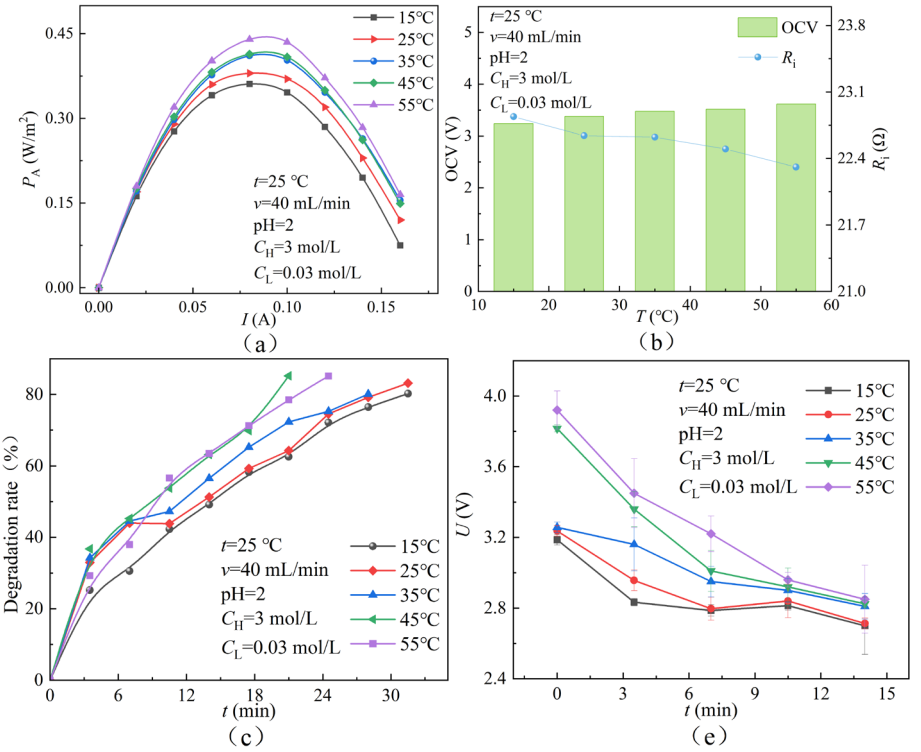

Fig. 3. Variation diagram of Cr(VI) reduction rate and performance of RED stack at different working solution temperatures.

Fig. 3 shows the effects of different working solution temperatures (15℃, 25℃, 35℃, 45℃, 55℃) on the reduction rate of Cr(VI), and the variation of the output performance of the stack with time. Fig. 3(a) shows the power density at different working solution temperatures. In short-circuit state, the maximum power density is 0.440 W/m^2 when the working solution is 55℃, and the minimum power density is 0.361 W/m^2 when the working solution is 15℃, with a difference of 0.079 W/m^2. Figure 3(b) shows the OCV and internal resistance at different working solution temperatures. It can be seen that the maximum OCV is 3.62 V at 55℃ and the minimum OCV is 3.24 V at 15℃, with a difference of 0.38 V. Figure 3(c) shows that the reduction rate of Cr(VI) increases with the increase of working solution temperature, and the reduction can be completed within 40 min.

Fig. 3 (d) reflect the law of the total power density and voltage of the loop changing with time. As the temperature of the working solution increases, both power density and voltage show an increasing trend. In the process of increasing temperature, the ionic activity increases, which leads to the increase of current density and voltage, and better reaches the reduction electromotive force of Cr(VI). Therefore, with the increase of working solution temperature, the reduction rate of Cr(VI) also increases.

4 Conclusion

In this paper, the influence of three core variables, concentration gradient, flow rate and temperature of working solution on Cr (VI) reduction process was systematically investigated under the condition of control variables. The experimental results reveal the following important laws: the output power density, open circuit voltage (OCV), total loop current density and voltage of the stack all show a significant increase trend with the gradual increase of the flow rate of the working solution, the continuous increase of the temperature and the continuous expansion of the concentration gradient. The essence of this phenomenon is that with the continuous increase of salinity gradient, the driving force of ions across the membrane has been significantly improved, so that the number of ions that can cross the membrane within a unit time has increased significantly, which further leads to a significant increase in the potential difference on both sides of the membrane, and then makes the electric potential at the electrode plate higher, providing more sufficient reduction electromotive force for the effective degradation of Cr(VI).

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