

Article

Electricity Generation, Salt and Nitrogen Removal and Microbial Community in Aircathode Microbial Desalination Cell for Saline-Alkaline Soil-Washing Water Treatment

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Abstract: An aircathode microbial desalination cell (AMDC) was successfully started by inoculating anaerobic sludge into the anode of a microbial desalination cell and then used to study the effects of salinity on performance of AMDC and effect of treatment of coastal saline-alkaline soil-washing water. The results showed that the desalination cycle and rate gradually shorten, but salt removal gradually increased when the salinity was decreased, and the highest salt removal was $98.00 \pm 0.12\%$ at a salinity of 5 g/L. COD removal efficiency was increased with the extension of operation cycle and largest removal efficiency difference was not significant, but the average coulomb efficiency had significant differences under the condition of each salinity. This indicates that salinity conditions have significant influence on salt removal and coulomb efficiency under the combined action of osmotic pressure, electric field action, running time and microbial activity, etc. On the contrary, COD removal effect has no significant differences under the condition of inoculation of the same substrate in the anode chamber. The salt removal reached $99.13 \pm 2.1\%$ when the AMDC experiment ended under the condition of washing water of coastal saline-alkaline soil was inserted in the desalination chamber. Under the action of osmotic pressure, ion migration, nitrification and denitrification, $\text{NH}_4^+\text{-N}$ and $\text{NO}_3^-\text{-N}$ in the washing water of the desalination chamber were removed, and this indicates that the microbial desalination cell can be used to treatment the washing water of coastal saline-alkaline soil. The microbial community and function of the anode electrode biofilm and desalination chamber were analyzed through high-throughput sequencing, and the power generation characteristics, organics degradation and migration and transformation pathways of nitrogen of the aircathode microbial desalination cell were further explained.

Keywords: aircathode microbial desalination cell; coastal saline-alkaline soil-washing water; salinity; desalination; pollutants removal; microbial community

1. Introduction

Soil nutrients usually include Cl^- , SO_4^{2-} , CO_3^{2-} , HCO_3^- , Na^+ , K^+ , Ca^{2+} , Mg^{2+} and other ions, which can promote the growth of plants and soil microorganisms. However, when ion concentration is too high, it will directly poison growth and indirectly interfere with normal physiological functions of plants and soil microorganisms [1,2]. Soil salinization is a serious land degradation problem

that affects soil, plants and groundwater within ecosystems, and the results showed that the mainly harmful ions were Na^+ and Cl^- [3]. Soil salinization seriously restricts the construction of ecological environment in coastal area. All these ions in the soil have the property of water solubility. In the process of washing the land, the salt ions dissolve in the water to improve the coastal saline-alkaline soil. However, at the same time, the salt in the water increases sharply, causing serious water resource pollution [4]. Coastal saline-alkaline soil-washing water—containing high salt, organics, nitrogen, etc.—has brought a heavy strain on freshwater resource protection. In addition, high salt adversely affects the life activity of aquatic plants, animals and humans, further disturbing aquatic ecology [5]. Thus, effective and simultaneous salt, pollutants removal from coastal saline-alkaline soil-washing water are essential before discharge. However, thus far, the researchers have paid much attention on desalination. There are three methods to remove salt ions from washing water: chemical method, biological method and physical method [6–8]. There is no study involving simultaneous desalination, pollutants removal from coastal saline-alkaline soil-washing water. China is a country with a serious shortage of freshwater resources, so it is very meaningful to study the recycling and utilization of coastal saline-alkaline soil-washing water.

Microbial desalination cells (MDCs) are a new type of technology developed from microbial fuel cells (MFCs) for the first time at Tsinghua University for power production, desalination and wastewater treatment [9]. Its concept of operation is similar to water electrodialysis, but the MDC is a device that uses bacteria as a catalyst to transform the chemical energy that exists in wastewater into electricity through electrochemical reactions. MDC employs an additional chamber that contains salty water between the anode and the cathode, containing ion exchange membranes separating the three chambers, and allowing salt ions to be extracted to achieve desalination [10–13]. After MDC was first invented by Cao et al., extended works have been successively reported, including stacked resin-packed MDC (SR-MDC) [14], treatment of chromium wastewater by new three-chamber microbial desalination cell [15], recirculation microbial desalination cell (rMDC) that avoided pH imbalances and bacterial respiration inhibition to increase power and achieve efficient desalination [16], microbial capacity desalination cell (MCDC) with the capacity can be regenerated through exchange the connection of electrode and activated carbon cloth assemblies [17], etc. Aircathode microbial desalination cell shows great potential in water desalination, wastewater purification and electricity generation due to its sustainability and stability [18–20]. However, most studies have so far have only investigated this with lab-scale designs, more importantly, for coastal saline-alkaline soil-washing water and its influence on desalination has never been explored.

For further study on scale-up device and broadening the practical application of MDC, it is worth investigating its performance and efficiency in saline-alkaline soil-washing water treatment. Studies have shown that salinity concentration is one of important conditions that could influence the performance of fuel cell due to its effect on the cell internal resistance, the electrode potential, the power production, the organic removal, conductivity and desalination performance, and so on [18,21,22]. Therefore, in the present study, a novel aircathode microbial desalination cell (AMDC) was constructed. It was to analyze the influence of different salinity concentration of high salinity at 30 g/L, medium salinity at 15 g/L, and low salinity at 5 g/L. Meanwhile, salt and pollutants degradation practicability of the AMDC was evaluated with coastal saline-alkaline soil-washing water treatment. Microbial communities were detected using 16S rRNA gene sequencing. In addition, the long-term operation stability of AMDC was also examined in terms of current output, power generation, columbic efficiency (CE), internal resistance and cell polarization to further evaluate its practicability.

2. Materials and Methods

2.1. AMDC Construction

The three chambers of the AMDC, namely anode, desalination, and cathode chambers, were constructed using an acrylic cube cut into 50-, 60- and 70-cm pieces, respectively, and separated with ion

exchange membranes. The three chambers had a total working volume of 630 L (Figure 1). The cation exchange membrane (CMI-Grion0011V, Lvhe Co., Ltd., Hangzhou, China) was used to separate the cathode chamber and desalination chamber. The anion exchange membrane (AMI-Grion0011V, Lvhe Co., Ltd., Hangzhou, China) were used to separate the anode chamber and desalination chamber, and both membranes had a cross-sectional area of 0.42 m². Preparations of AEM, CEM and electrodes were according to the description in previous study and the manufacturer's instructions; the membranes were left in 5% NaCl solution for 48 h to allow hydration and expansion before installation [23]. Both the anode and cathode electrodes material were carbon cloths (B1B, E-Tech, Troy, PA, USA) with a dimension of 50 by 60 cm, and pre-treated with 15% *v/v* acetone solution for 24 h before use to remove the grease stain on the machined surface. Electrodes were immersed in distilled water before experiments and, then, rinsed with deionized water [24,25]. An external electric circuit was connected by connecting a titanium wire coupled with an external a resistor (1000 Ω).

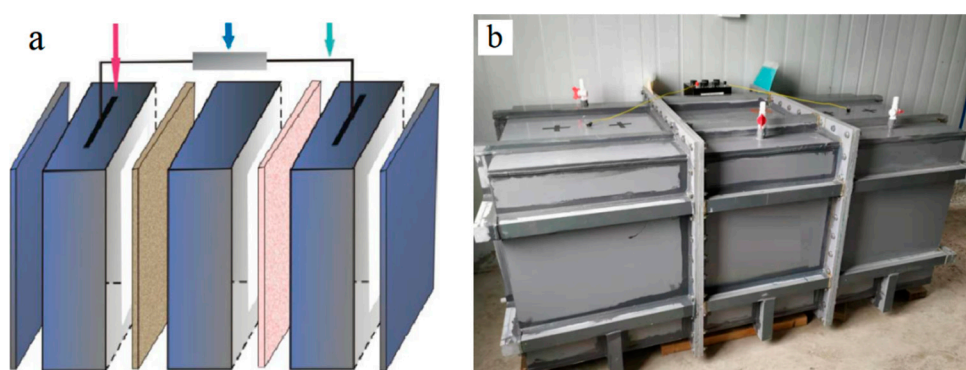


Figure 1. Schematic diagram of aircathode microbial desalination cell (a) and physical photo (b).

2.2. System Inoculation

According to previous studies [25,26], to further reduce the start-up period and operating costs of the AMDC, the anode chamber was directly inoculated with aerobic sludge collected from second sedimentation in a local wastewater treatment plant (Lingang New City, Shanghai, China). The ratio of aerobic sludge and nutrient solution (contained 0.56 g·L⁻¹ C₆H₁₂O₆, 4.40 g·L⁻¹ KH₂PO₄, 3.40 g·L⁻¹ K₂HPO₄ and 0.32 g·L⁻¹ NH₄Cl) was 1:1, and it was sealed and subjected to constant temperature (30 °C) in a water bath for a few days to obtain anaerobic sludge as an anode chamber inoculation of microorganisms. The volume of sludge mixture used as inoculum was 50% of the total anode chamber volume. The inoculum process continued at the start-up of AMDC until reaching a stable system performance. Coastal saline-alkaline soil-washing water was acquired from a washing water treatment pool in coastal saline-alkaline soil (30°55′3.49″ N, 121°58′29.28″ E) adjacent to the East Sea. Coastal saline-alkaline soil-washing water composition was salt solution: 6.88 ‰ (equal to 6.88 g/L salinity), COD: 25.85 ± 1.1 mg/L, pH: 6.13 ± 0.08, total nitrogen (TN, 2.7 ± 0.32 mg/L), ammonium nitrogen (NH₄⁺, 1.51 ± 0.21 mg/L), nitrate nitrogen (NO₃⁻, 2.34 ± 0.16 mg/L), total phosphorus (TP, 0.13 ± 0.06 mg/L). To ensure the adequate electron donor, the anode chamber was fed with a glucose based simulative wastewater (COD, 600 mg/L) as fuel containing C₆H₁₂O₆ (0.56 g/L), KH₂PO₄ (4.40 g/L), K₂HPO₄ (3.40 g/L) and NH₄Cl (0.32 g/L), pH was 6.67, while the cathode chamber contained KH₂PO₄ (4.40 g/L), K₂HPO₄ (3.40 g/L), NH₄Cl (0.32 g/L) and NaHCO₃ (1.92 g/L), which was aerated continuously by an aerator to increase dissolved oxygen (DO). Cathodic DO concentration was kept at values greater than or equal to 6.0 mg/L by adjusting the flow aerator [27], pH is 6.67. The middle desalination chamber was filled with artificial saltwater containing 30, 15, and 5 g/L NaCl solution.

2.3. Experimental Operation

The common wastewater treatment process has an average hydraulic retention time from 12 to 48 h [25]. Once the system voltage was below to 100 mV, and the electrolytes solution in anode and cathode were replaced [28]. Therefore, a 48-h batch cycle is chosen as reasonable cycle to investigate the system performance in this study. 30 g/L NaCl solution was set in the middle desalination chamber. After successful start-up, high-salinity solution, medium-salinity solution, low-salinity solution and fresh coastal saline-alkaline soil-washing water were successively injected into the middle desalination chamber to carry out a complete desalination cycle. For long-term evaluation, the experiments were continuously operated over a period of 50 days (1200 h) at 25 ± 1 °C including the start-up [29].

2.4. Experimental Test and Analysis

Determination of water quality indicators: conventional water quality indicators such as chemical oxygen demand, ammonia nitrogen, nitrate nitrogen of water inlet and outlet of the cell are measured according to standard methods [30,31]. NaCl concentration and conductivity was monitored by using the multi-parameter water quality analyzer (HACH, HQ40D, Loveland, CO, USA).

Determination of electrochemical characteristics: the voltage was recorded every 1 min by an 8-channel data acquisition system (RTKINS Co., Ltd., Wuhan, China) connected to a computer, and the averages were calculated per 1 h. Its reading was recorded when a steady state at each resistance value was achieved. Then, power generation, current density (A/m^2) and power density (mW/m^3) were calculated and reported to the area of electrode and the net total working volume. The polarization curves were obtained by varying the external resistance from 1000 to 50 Ω (the external resistances were, respectively, 1000, 500, 300, 200, 100, 50 Ω) as described by Qu et al. [32]. The internal resistance was obtained from the polarization curve as described by Logan et al. [33]. The coulombic efficiency (CE) was used to characterize the electrical capacity of the anode microorganisms. Excel 2007 was used for data sorting and mapping, and SPSS 17 software was analyzed statistically.

Microbial community determination: after the end of the experiment, the microbial community structure in the anode electrode biofilm (carry out a DNA extraction from the electrodes) and the water in the desalination chamber was analyzed, and the bacteria genera with relative abundance greater than 1% were taken as the main bacteria genus. In this study. The primers sets used were 338F (ACTCCTACGGGAGGCAGCA) and 806R (GGACTACHVGGGTWTCTAATAT). The V3–V4 regions of the bacterial 16S rRNA gene analysis was performed in this study on an Illumina MiSeq platform (Personal Biotechnology Co., Ltd., Shanghai, China) [34].

3. Results and Discussion

3.1. Impact of Salinity on Performance and Start Up of AMDC

3.1.1. Start-Up of AMDC

The cell was operated in fed-batch mode at a temperature of 25 ± 1 °C, and the desalination chamber was filled with 30 g/L of NaCl solution. The dynamic changes in the output voltage trend over time during the operation of the AMDC are shown in Figure 2. The output voltage exceeded 600 mV for three consecutive periods and tended to be stable. The cell start-up phase was complete after 8 days of culture, and the maximum voltage was ~702 mV.

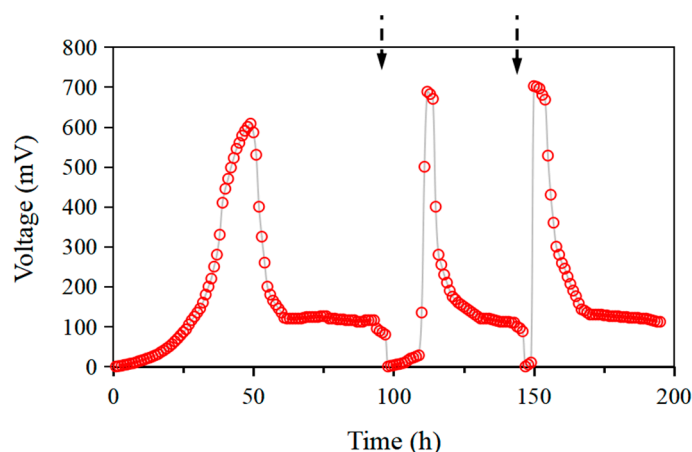


Figure 2. Voltage output of the AMDC (arrows indicate replacement of substrate solution).

During the stable power production stage of the experiment, polarization measurements were made using a variable resistor box, and the external resistance was reduced stepwise from 1000 to 50 Ω (the external resistances were, respectively, 1000, 500, 300, 200, 100, 50 Ω). The output voltage value, current density and volume power density were recorded and calculated by the area of electrode and the effective volume of the cell. The power density and polarization curves are shown in Figure 3.

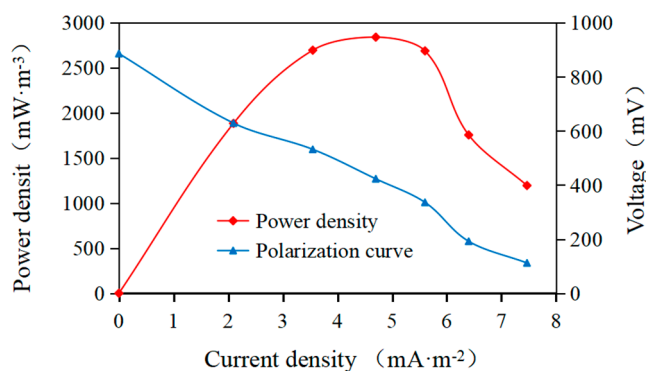


Figure 3. Power density curve and polarization curve of the AMDC.

As can be seen in Figure 3, the maximum power density of AMDC at 30 g/L salinity is 2.84 W/m³ now (current density is 4.70 mA/m²), which is significantly higher than the maximum power density of 2.27 W/m³ obtained by Mehanna et al. at 20 g/L salinity of a three-chamber air cathode microbial desalination cell [18]. The power density of the cell depends on the system polarization, which is determined by both anode and cathode polarization [35]. Meanwhile, the desalination chamber with high salinity has higher conductivity, which can effectively promote the transfer of salt ions, accelerate the operation of the reactor and improve the effect of desalination. The cell ohm internal resistance is 71.48 Ω by polarization curve. Under the influence of the ionic strength of the solution, the electrode, wire and separator will cause certain ohmic loss, and ohmic internal resistance will affect the output voltage and power density.

3.1.2. Desalination Performance under Diverse Salinity Concentrations

Under different influent salinity, the concentration change and desalination rate of the NaCl solution in the desalination chamber are shown in Figure 4, and the concentration gradient desalination is considered to be over when the salinity drops more than 95%. It can be seen from Figure 4 that the salt removal can reach above 95% under different salinity, but the time required to remove the same salinity varies greatly. At the end of the experiment, under the salinity of 30, 15 and 5 g/L,

the desalination time was 13, 7 and 4 d, the desalination rate was 2.21, 2.09 and 1.23 g/d, respectively, and the salt removal was $95.83 \pm 0.21\%$, $97.60 \pm 0.16\%$ and $98.00 \pm 0.12\%$, respectively.

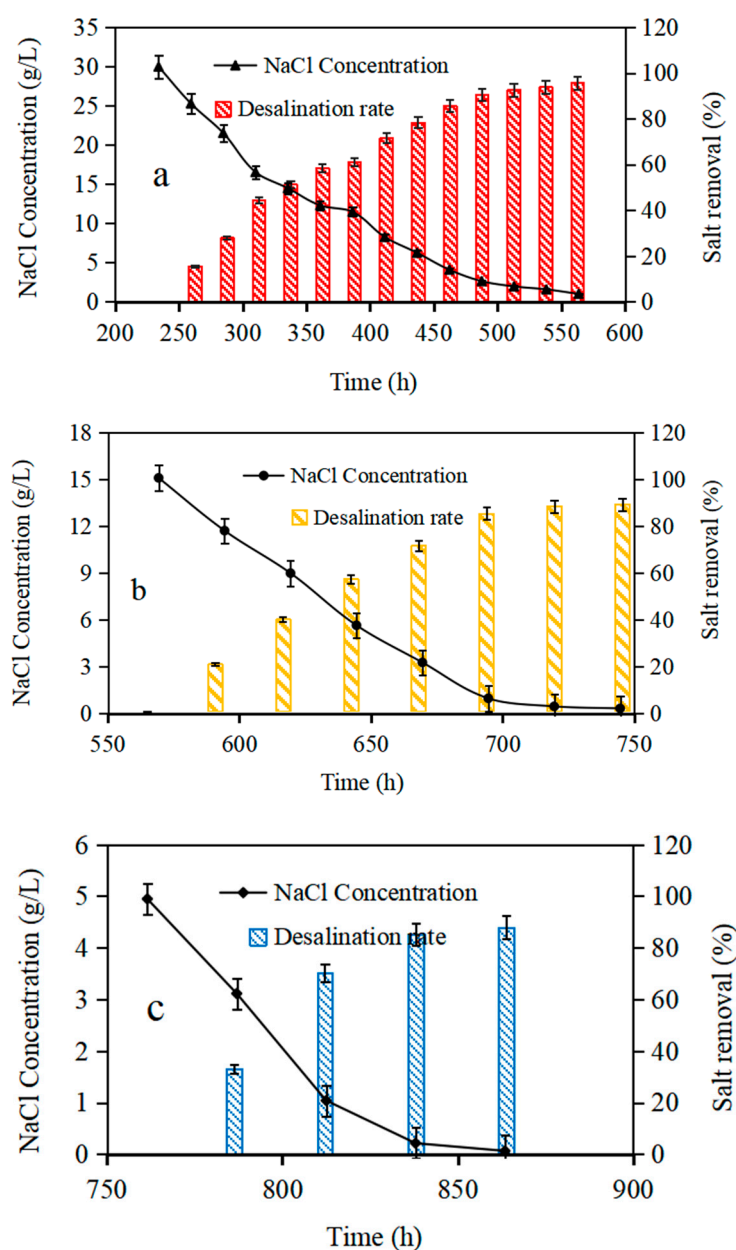


Figure 4. Change in NaCl concentration and salt removal of the AMDC ((a) 30 g/L, (b) 15 g/L, (c) 5 g/L salinity).

The results show that the desalination cycle and rate become shorter and the salt removal increases as the salinity decreases of the desalination chamber, and the salt removal is the highest at 5 g/L salinity. The decrease of salt concentration in desalination chamber was mainly caused by osmotic pressure and electric field action. Na^+ and Cl^- migrated to the cathode chamber and the anode chamber respectively under the electric field action. When the conductivity of the anode chamber is lower than that of the desalination chamber, there is an osmotic pressure difference between the anode chamber and the desalination chamber. At this point, the osmosis and electric field jointly cause the salt concentration in the desalination chamber to fall. With the decrease of salinity, the ionic strength and osmotic pressure difference between the anode chamber solution and the desalination chamber become smaller, the osmotic effect decreases and the salt removal becomes slower. On the contrary, the desalination

cycle increases and the salt removal decreases with the salinity of desalination chamber increasing. Due to the low salinity of the water in the desalination chamber, the ionic strength and electrical conductivity continuously decrease with the prolongation of time, leading to the ohmic resistance of the desalination chamber and the decrease of the current. Under the action of the electric field, the ion migration is slow, and the conductivity difference between the anode chamber and the desalination chamber was reduced and the osmotic effect was weakened.

3.1.3. Organic Removal and Coulomb Efficiency under Diverse Salinity Concentration

The nutrient solution of anode chamber was replaced every 48 h, the COD removal effect and coulomb efficiency were shown in Figure 5 under different salinity conditions in the desalination chamber. As can be seen from Figure 5a, the COD removal rate gradually increased from 225.5 ± 1.2 mg/(L·day) in the 6th cycle to 264.0 ± 1.5 mg/(L·day) in the 11th cycle under the salinity of 30 g/L. According to Figure 5b, under the salinity of the desalination chamber of 15 g/L, COD removal rate gradually increased from 251.5 ± 2.0 mg/(L·day) in the 13th cycle to 265.0 ± 0.9 mg/(L·day) in the 15th cycle in the stable phase. According to Figure 5c, under the salinity of the desalination chamber of 5 g/L, COD removal rate gradually increased from 265.0 ± 2.1 mg/(L·day) in the 17th cycle to 266.0 ± 1.4 mg/(L·day) in the 18th cycle in the stable phase. As can be seen from Figure 5d, the maximum coulomb efficiency under the salinity of 30, 15 and 5 g/L was $13.91 \pm 0.5\%$, $17.60 \pm 0.2\%$ and $18.53 \pm 0.7\%$, respectively.

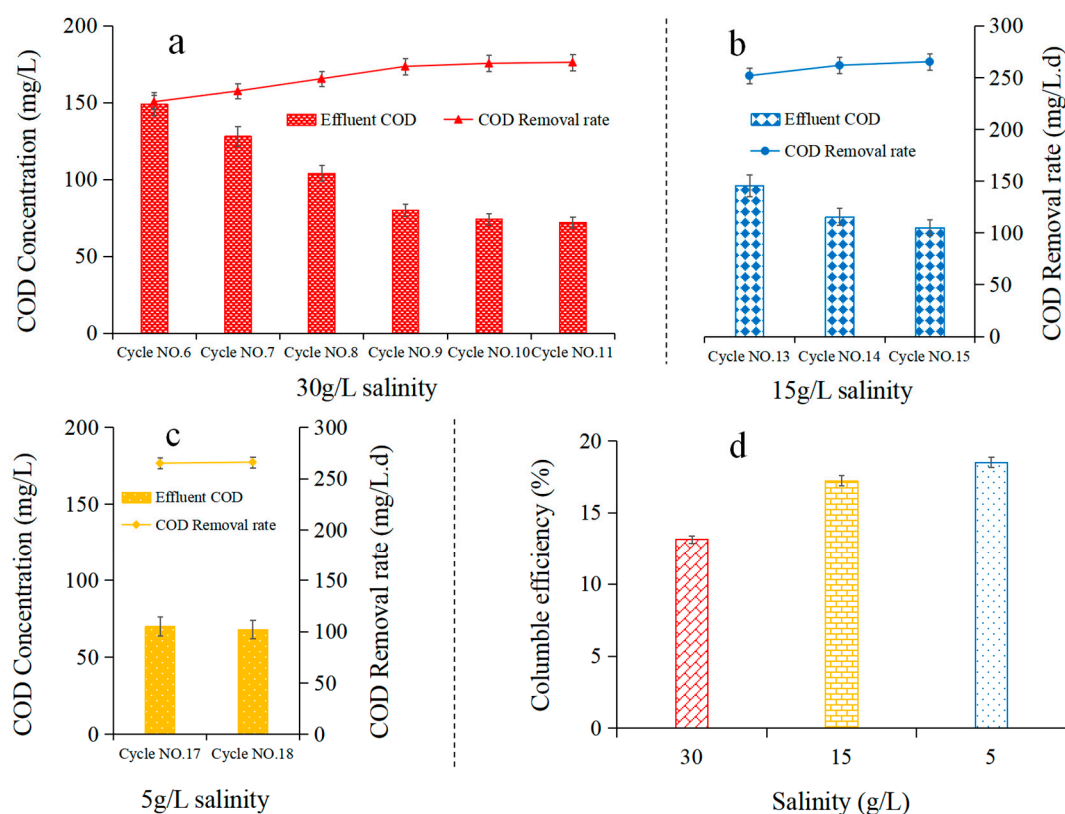


Figure 5. COD removal rate ((a) 30 g/L, (b) 15 g/L, (c) 5 g/L salinity) and coulomb efficiency (d) of the AMDC.

The results showed that COD removal rate at each salinity increased and tended to be stable with the extension of the operating cycle, but the maximum COD removal rate at each salinity showed no significant difference ($p > 0.05$), which was consistent with the results of inoculation of the same substrate and consistent with previous studies [27]. The maximum coulomb efficiency of the desalting chamber with salinity of 5 g/L is higher than that of the other two. As mentioned above, the desalination

cycle of higher desalination chamber salinity is longer. With the increase of running time, the anode biofilm gradually matures and the microorganisms gradually adapt to the living environment. It is possible that, due to the excessive increment of non-electric-producing bacteria in this process and the large consumption of substrate organic matter, the coulomb efficiency decreases with the prolonging of desalination time under the high desalination chamber salinity.

3.2. AMDC Treatment Results and Analysis of Saline-Alkaline Soil-Washing Water

3.2.1. AMDC Power Generation and Desalination Efficiency

The voltage output and desalination efficiency of the AMDC desalination chamber are shown in Figures 6 and 7 under the condition that the actual coastal saline-alkaline soil-washing water. After six cycles of operation, the peak voltage was ~ 742 mV at open-circuit state, and the salt removal of AMDC at the end of operation was $99.13 \pm 2.1\%$. Studies have shown that low-salinity wastewater charge accumulation in wastewater can be solved as well as the negative impact of ohmic losses, overcoming the high-salinity wastewater as the substrate system's low conductivity; in the long-run conditions, low salinity caused actual coastal saline-alkaline soil-washing water to obtain high desalination efficiency, and the aircathode microbial desalination cell reached the requirement of the required in terms of desalination.

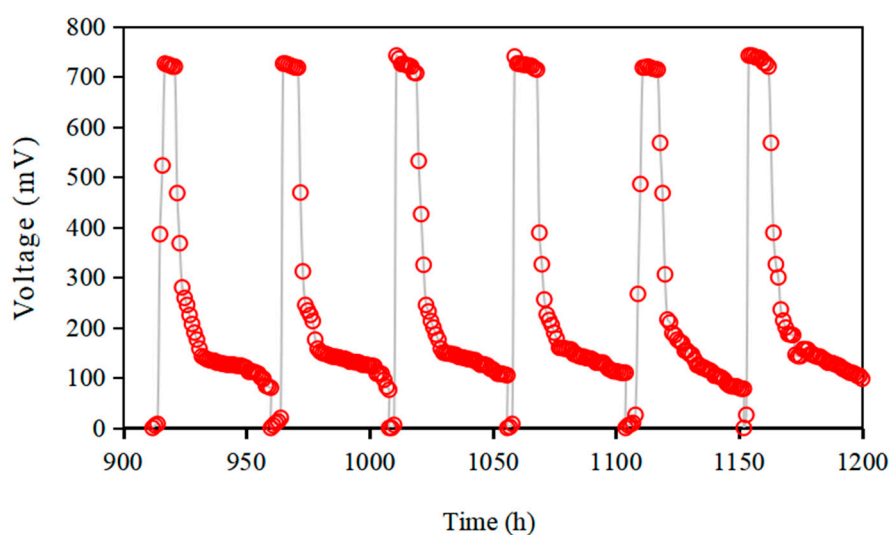


Figure 6. Voltage output versus time in the AMDC with coastal saline-alkaline soil-washing water.

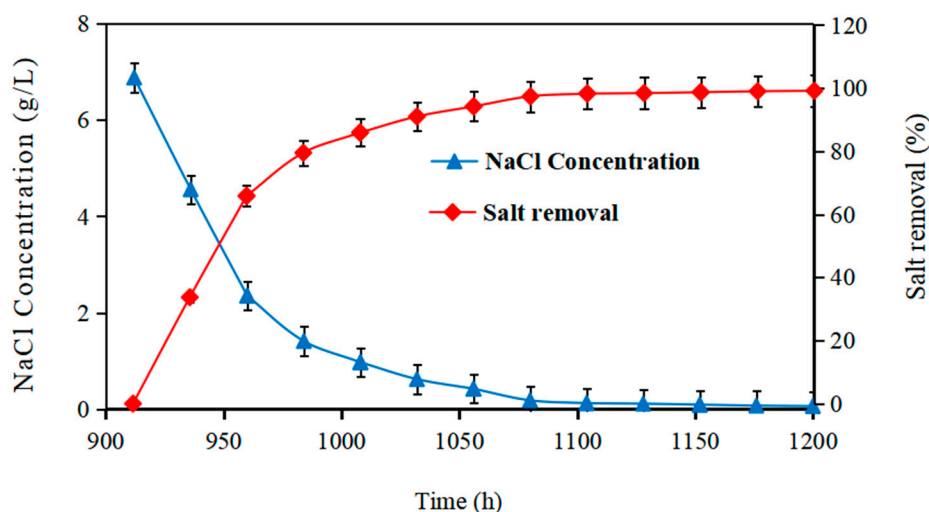


Figure 7. Salt removal versus time in the AMDC with coastal saline-alkaline soil-washing water.

3.2.2. Change Efficiency in Inorganic Nitrogen Concentration of the AMDC

During the operation phase of AMDC in the wash water inlet of coastal saline-alkaline soil, the substrate of the anode chamber was the activated sludge mixed with glucose. At the end of operation, the change rate of AMDC inorganic nitrogen concentration is shown in Table 1 and Figure 8. The removal rates of ammonia nitrogen in anode chamber, cathode chamber and desalination chamber were $70.88 \pm 0.15\%$, $82.11 \pm 0.18\%$ and $78.68 \pm 0.20\%$, respectively; the removal rates of nitrate nitrogen were $12.52 \pm 0.04\%$, $6.72 \pm 0.02\%$ and $-16.49 \pm 0.03\%$, respectively.

Table 1. Influent and effluent concentrations in inorganic nitrogen concentration of the AMDC.

Location	Mode	pH	Ammonium (mg/L)	Nitrate Nitrogen (mg/L)
Anode chamber	Influent	6.67 ± 0.01	42.72 ± 2.15	2.39 ± 0.18
	Effluent	5.77 ± 0.03	12.44 ± 0.15	2.09 ± 0.04
Desalination chamber	Influent	6.13 ± 0.08	1.51 ± 0.21	2.34 ± 0.16
	Effluent	6.04 ± 0.01	0.27 ± 0.18	2.18 ± 0.02
Cathode chamber	Influent	6.92 ± 0.04	18.67 ± 0.84	0.97 ± 0.05
	Effluent	7.82 ± 0.04	3.98 ± 0.20	1.13 ± 0.03

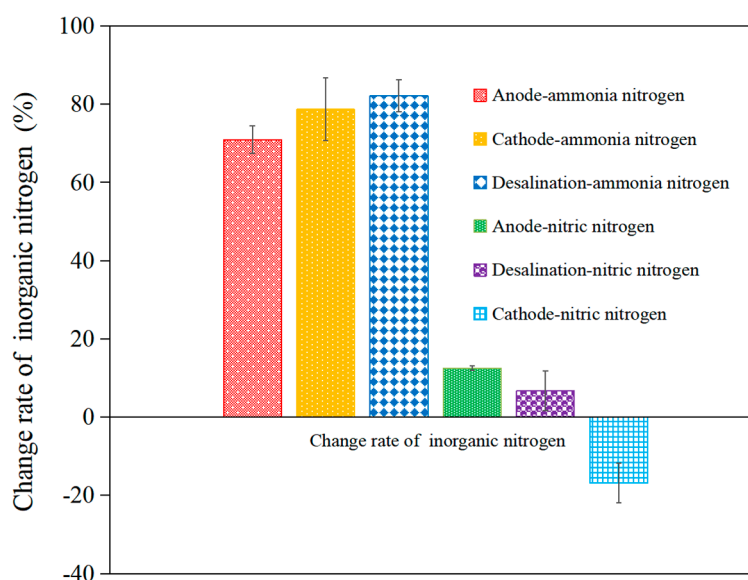


Figure 8. Change efficiency in inorganic nitrogen concentration of the AMDC.

During the whole process, NH_4^+ was converted in the anode chamber to reduce the content of NH_4^+ in the solution under the action of denitrification anaerobic ammonia oxidation, and NH_4^+ was transferred to the cathode chamber through the cation exchange membrane in the desalination chamber. At the same time, the desalination chamber may contain denitrifying bacteria from washing water. Under the combined action of denitrification and ion migration, NH_4^+ -N in the desalination chamber can be removed, and the removal rate is higher than that in the anode chamber [36]. After NH_4^+ in the desalination chamber is transferred to the cathode chamber, nitrification takes place under higher dissolved oxygen conditions and is converted into NO_3^- -N, which makes the concentration of NO_3^- in the cathode chamber rise and shows a higher negative removal rate. Under the action of infiltration and electric field, NO_3^- in the washing water of the desalination chamber is transferred to the anode chamber, resulting in the decrease of NO_3^- -N in the washing water, but lower than the removal rate of NO_3^- -N in the anode chamber. It is possible that the migration rate and denitrification rate of NO_3^- in washing water are lower than that of NO_3^- in the anode chamber, which is closely related to the denitrification of a small part of NO_3^- -N in the desalination chamber [37]. Therefore, in order to further explain the nitrogen migration and transformation pathway in the microbial desalination cell,

high-throughput sequencing was used to sequence the anode electrode biofilm and the microorganisms in the desalination chamber water, explaining the ammonia nitrogen removal pathway in the actual coastal saline-alkaline soil-washing water.

3.3. Analysis of Microbial Community Diversity

3.3.1. Microbial Diversity Index

As the core of the air-cathode microbial desalination cell, microorganisms play an important role in generating electricity and removing pollutants in the process of bio-catalytic reaction. Through the sequencing analysis of 16S rRNA gene library, the microbial community structure in the water body of AMDC reactor anode electrode biofilm and desalination chamber was analyzed, and was divided according to the homology of 97%.

The results showed that the microbial richness in the anode electrode biofilm was greater than that in the desalination chamber and showing more OTU. On the contrary, the evenness of the microbial community composition in the water of the desalination chamber is slightly better than that of the anode electrode biofilm, and the abundance difference among OTUs in the community is small. The richness and diversity of the two are different, which is caused by the different growth environment of microorganisms in the anode chamber and desalination chamber. The microbial Shannon index in the water of the anode electrode biofilm and desalination chamber was 7.99 and 7.45, respectively.

3.3.2. Microbial Communities in the Genus Levels

Illumina Miseq sequencing platform was used to analyze the microbial community structure in the anode electrode biofilm of the aircathode microbial desalination cell and the water of the desalination chamber. The main bacteria genera in the water of the desalination chamber and the anode biofilm are shown in Figure 9.

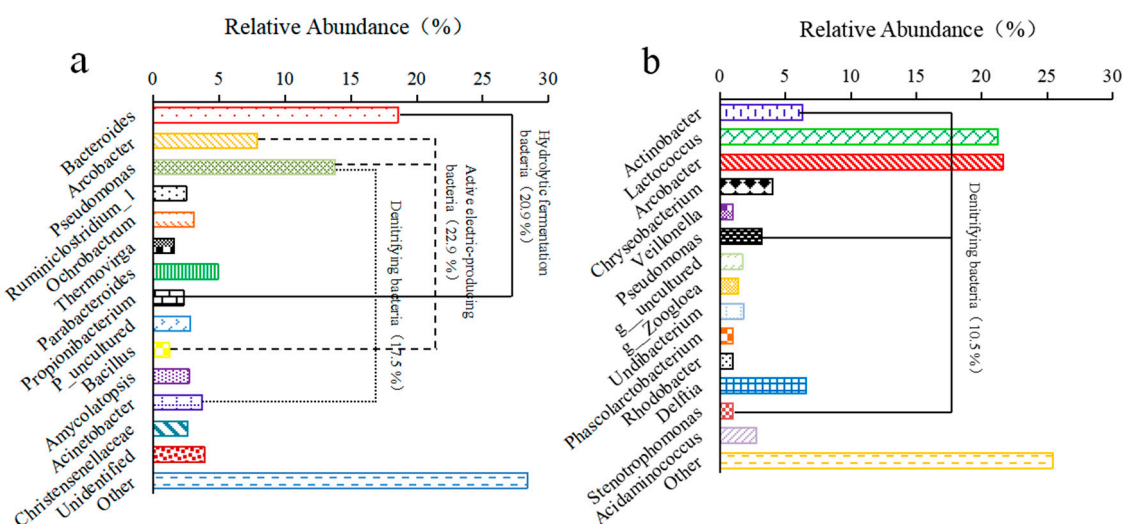


Figure 9. Microbial communities of anode electrode (a) and the water of the desalination chamber (b) in the genus levels.

The dominant species of anode biofilm were *Bacteroides* (18.6%), *Pseudomonas* (13.8%) and *Arcobacter* (7.9%). The dominant bacteria were *Arcobacter* (21.6%), *Lactococcus* (21.2%) and *Actinobacter* (6.3%). Figure 9a shows that a total of three electroactive bacteria were found in the anode membrane, namely *Pseudomonas* (13.8%) [38], *Arcobacter* (7.9%) [39] and *Bacillus* (4.6%) [40]. The total abundance of the electrochemically active bacteria was 22.9%. *Pseudomonas* belongs to the genus of heterotrophic denitrifying bacteria under the *Proteobacteria*, and is also one of the typical and most common electrochemically active microorganisms. It is widely found in the anaerobic biological anodes of

microbial fuel cells such as brewery and pig wastewater treatment, realizing the cell's power production function [41]. At the same time, two species of hydrolyzed fermentation bacteria were found in the anode membrane, namely *Bacteroides* (18.6%) and *Propionibacterium* (2.3%), and the total abundance of hydrolyzed fermentation bacteria was 20.9%. Through the metabolism of organic matter, glucose or xylose can be fermented as small molecules of mixed acid, accelerate the metabolism of electroactive bacteria to the common matrix, improve the activity of electroactive bacteria [42–44]. Combined with the situation of COD degradation, it can be inferred that a large amount of glucose fermentation bacteria consume the anode substrate but produce no electric energy, resulting in a high COD removal rate in the reactor, but the cell output voltage and ohmic internal resistance are not ideal. In addition, two denitrifying bacteria genera were found in the anode membrane, *Pseudomonas* (13.8%) and *Acinetobacter* (3.7%), the total abundance of denitrifying bacteria was 17.5%. Such denitrifying bacteria have denitrifying function and participate in nitrogen transformation, which is one of the main reasons for the rapid removal of $\text{NH}_4^+\text{-N}$ and $\text{NO}_3^-\text{-N}$ in the anode chamber [45–47].

According to Figure 9b, three denitrifying bacteria of *Pseudomonas* (3.2%), *Acinetobacter* (6.3%) and *Stenotrophomonas* (1%) were found in the desalination chamber, and the total abundance of denitrifying bacteria was 10.5%. The abundance of denitrifying bacteria in the water of the desalination chamber is lower than that in the anode biofilm, which is the reason why the removal rate of $\text{NO}_3^-\text{-N}$ in the desalination chamber is slightly lower than that in the anode chamber. Of course, this also explains the removal of $\text{NO}_3^-\text{-N}$ in the desalination chamber not only because of the concentration difference, but also the denitrification reaction under the action of denitrifying bacteria.

4. Conclusions

- (1) Salinity conditions affect the performance of microbial desalination cell. With the decrease of salinity, the desalination cycle and rate become shorter and the salt removal increases. At higher salinity, salt ion transfer in the desalination chamber leads to charge accumulation and longer desalination time. Low-salinity wastewater can solve the negative effects of charge accumulation and ohmic loss in wastewater, and overcome the low conductivity problem of high-salinity wastewater as the system substrate.
- (2) The experimental results show that the pollutants removal rate and desalination effect of AMDC can meet the conditions when it is used to treat the actual coastal saline-alkaline soil-washing water, but the output power cannot meet the actual demand, and there is a limit of water treatment. AMDC can assist in the primary desalination of brine such as coastal saline-alkaline soil-washing water, or the secondary desalination of water after the initial desalination of water treatment equipment. However, as an independent application of desalination equipment in engineering projects, the effect has not yet been achieved, which needs further research and improvement.

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