Integration of anaerobic digestion and electrodialysis for methane yield promotion and ammonium in-situ recovery

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Introduction:

Anaerobic digestion (AD), which converts organic matter in organic wastes (animal manure, agricultural by-products, organic wastes, etc.) to biogas, provides a clean route to produce renewable bioenergy, thus playing a critical role in the climate-neutral economy. Adoption and application of AD can be improved by addressing two challenges: one is methane (CH_4) production inhibition by high ammonium (NH_4^+) concentration and the other is digestate disposal (Choudhury et al., 2022). This study aims to develop a novel AD technology for high CH_4 production efficiency by in-situ NH_4^+ recovery with electrodialysis technology (ED). The feasibility of ED in NH_4^+ recovery from digestate has been justified with our preliminary study (Meng et al., 2022; Shi et al., 2019). Thus, this study will investigate the feasibility of the proposed ED-integrated AD system (ADED) for NH_4^+ in-situ recovery and methane yield promotion. The proposed ADED technology could bring the following advantages: (1) ED utilisation can recover NH_4^+ from the AD digesters as the fertiliser; (2) NH_4^+ recovery can promote the CH_4 yield and improve the digesters' loading rates and economic viability; and (3) NH_4^+ recovery can avoid its volatilisation in digestate land spreading.

Materials and methods:

A 2 L AD reactor was used, which integrated with a 3 repeating units ED stack for NH_4^+ recovery, as shown in Fig. 1. To avoid particles in the AD sludge to block the ED chamber, a mesh column was used to retain the particles in AD substrate, which allowed the diffusion of the ions for ED recovery. Also, a conventional AD reactor was set as a control group. Both reactors were operated at a condition of 35 ºC.
The reactors were seeded with 12.5 g/L of anaerobic sludge, accounting for 5.0 g/L suspend solid sludge in the AD reactor. The synthetic wastewater was fed to the AD reactor, which consisted of 5,000 mg/L glucose, 19,107 or 38,214 mg/L NH_4Cl corresponding to NH_4^+-N concentrations of 5,000 mg/L and 10,000 mg/L respectively, 10,000 mg/L $NaHCO_3$, 200 mg/L $MgCl_2$, 100 mg/L $CaCl_2$, 140 mg/L Na_2HPO_4, 1 mg/L $FeCl_2 \cdot 4H_2O$, and trace elements. The trace elements consisted of $MnCl_2 \cdot 4H_2O$, $NaMoO_4 \cdot 2H_2O$, H_3BO_3, $NiCl_2 \cdot 6H_2O$, $NaWO_4 \cdot 2H_2O$ and Na_2SeO_3, with 0.5 mg/L of each.

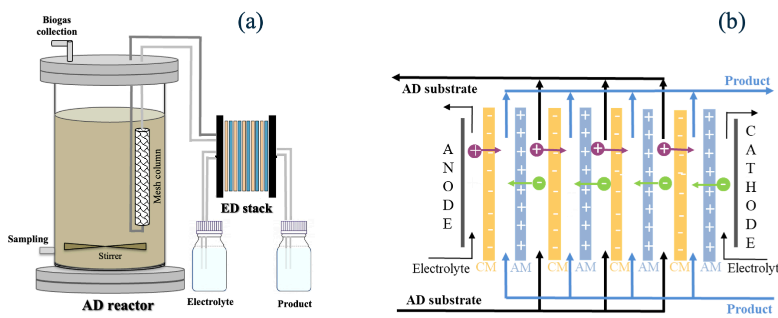

Fig. 1. Schematic diagram of the proposed ADED system (a), and ED stack (b)

Results and discussion:

ED was integrated into the AD system to control NH_4^+ concentration, which was operated when the AD system had a high NH_4^+ concentration. This study investigated the ADED performance with 2 scenarios; one was that AD feedstock had a high NH_4^+-Nconcentration of 5,000 mg/L, and the other was that the AD feedstock had an ultra-high NH_4^+-N concentration of 10,000 mg/L. As shown in Fig. 2, at NH_4^+-N of 5,000 mg/L, the ED was operated for 150 min on the first day. After the ED operation, the NH_4^+-N concentration decreased from 4,668 mg/L to 1,358 mg/L and stabilized around 1,350 mg/L during the first operation batch. In the following batches, the NH_4^+-N concentration was reduced to around 1,600 mg/L after the ED operation. In contrast, the NH_4^+-N concentration in the control reactor was stabilized at around 4,800 mg/L.
When the influent NH_4^+-N was 10,000 mg/L, the ADED reactor was kept at a low level of ~2,000 mg/L after the ED operation. In contrast, the NH_4^+-N concentration in the control reactor was stabilized at ~9,500 mg/L. Those results indicated ED integration can recover NH_4^+ from the AD digestate and control NH_4^+ concentration at a low level.

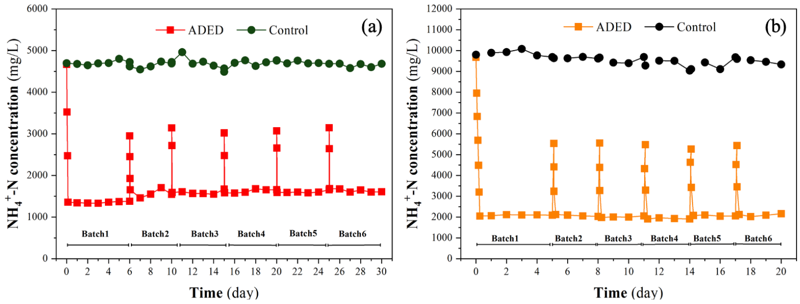

Fig. 2 Variation of NH_4^+-N concentration in AD digestate: in the condition of 5,000 mg/L influent NH_4^+-N (a) and 10,000 mg/L influent NH_4^+-N (b)

AD performance was further investigated in terms of CH_4 production. The daily CH_4 yield and accumulated CH_4 yield are shown in Fig. 3. In the condition of 5,000 mg/L NH_4^+-N, the CH_4 yield of the control reactor on the first day was low at 0.1 L, which may be because the high NH_4^+ concentration impacted the activity of methanogens. After one day of adaption, the CH_4 daily yield increased to around 0.45 L. In contrast, the ADED reactor did not have a lag time of CH_4 yield and produced 1.75 L CH_4 in the first 3 days. After 6 batches of operation, the ADED reactor produced 9.4 L CH_4 in total, which is 1.42 times that control group of 6.6 L. It indicated that the NH_4^+-N toxicity was released after removing NH_4^+ from the AD substrate.

In the condition of 10,000 mg/L NH_4^+-N, the methanogens were inhibited as the slight CH_4 yield in the control reactor. While the ADED group had a high daily CH_4 yield (~0.5 L), and produced more than 6.0 L CH_4 during 6 batches. It indicated that ED could release NH_4^+ toxicity and make the AD treating the wastewater with high NH_4^+ concentration possible.

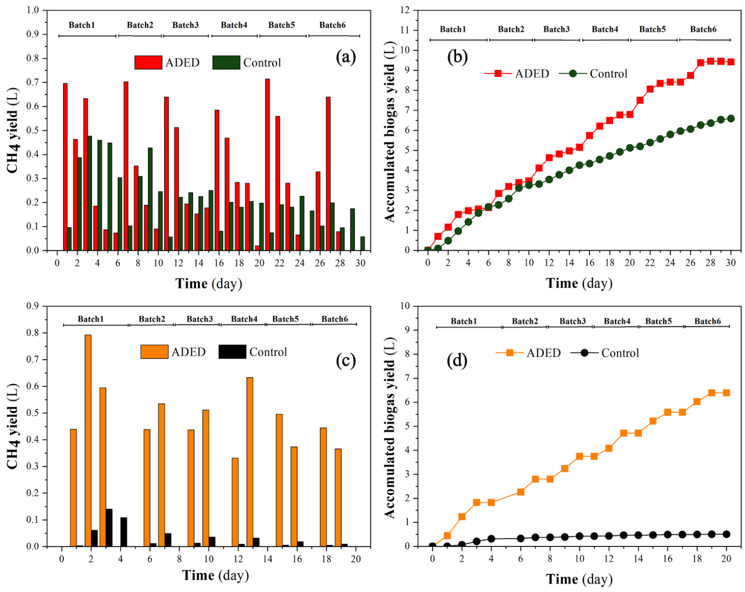

Fig. 3 Daily CH_4 yield (a) and accumulated CH_4 yield (b) in the 5,000 mg/L influent NH_4^+-N, and daily CH_4 yield (c) and accumulated CH_4 yield (d) in the 10,000 mg/L influent NH_4^+-N

Conclusion

This study verified the feasibility of ADED technology. The results indicated that the integration of ED can recover NH_4^+ from the AD reactor and release NH_4^+ toxicity. ADED promoted CH_4 yields by more than 1.42 times in the condition of 5,000 mg/L NH_4^+-N, and released NH_4^+-N toxicity in the condition of 10,000 mg/L NH_4^+-N.

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