Nutrient recovery from digestate using electrodialysis technology

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Introduction

As the world intensifies efforts to combat climate change, achieving carbon neutrality has become a critical goal for many nations, with the biomethane strategy playing a key role. Biomethane is a renewable energy and produced by anaerobic digestion (AD) of biowastes and agricultural by-products. The digestate, a by-product of AD, needs to be properly managed to achieve this strategy. While land application of digestate is commonly practiced as fertilizer for crops, it has been shown to risk the environment through nutrient leaching and runoff. Particularly in Ireland, soil phosphorus contents limit the application of digestate on land[1]. In response to these challenges, we have developed the novel electrodialysis (ED) technologies to recover nutrients from manure digestate, thereby improving the sustainability of AD.

Methodology

To achieve this goal, laboratory-scale bipolar membrane electrodialysis (BMED) system was set up to evaluate the feasibility of recovering of ammonium (NH_4^+), phosphate (PO_4^{3-}), and volatile fatty acids (VFA) from pig manure hydrolysate for the first time. Subsequently, a bench-scale electrodialysis reversal (EDR) system was carried out to assess its potential for long-term operation in terms of recovery efficiency and membrane fouling. Furthermore, an innovative anode-ED technology was developed for in-situ disinfection and antibiotic removal to enhance biosafety.

Results and discussion

The recovery efficiencies of NH_4^+, PO_4^{3-}, and VFA were 78%, 75% and 87%, respectively, confirming the feasibility of the BMED operation strategy [2]. However, attention needs to be paid to membrane fouling, which may occur after a long-term operation. Specifically, in manure digestate, organic matter composed of humic-like and tyrosine-like substances, can foul anion-exchange membrane through electrostatic interactions [3]. Particularly pollutants with molecular sizes smaller than 10 kDa was found to lead to irreversible internal fouling [4]. To mitigate the membrane fouling, different strategies for fouling cleaning were explored, including EDR technology and chemical cleaning. The results showed significant mitigation of particle and chemical deposition, with organic foulants primarily confined to the membrane surface, rather than migrating deeper into the membrane [3]. Thus, EDR was proven to be effective for mitigating both inorganic and organic fouling. Based on this finding, the EDR system demonstrated stable performance during long-term operation under a treatment load of 5000 L/m^2, achieving over 80% recovery of NH_4^+ despite minor membrane fouling and fluctuations in PO_4^{3-} recovery, as shown in Figure 1. Figure 2a shows that using the anode-ED technology, around 49% of sulfadiazine (SD) and 64% of tetracycline (TC) contained in the pig manure was removed with efficient recovery of NH_4^+ and PO_4^{3-}. Anode-ED was also efficient in removing 17β-estradiol, with the removal efficiency of up to 86.7 ± 3.4%. Besides nutrient recovery and removal of emerging contaminants, this technology can also inactivate pathogenic microorganisms, and mitigate membrane fouling, producing water that can be reclaimed for farm yard usage [4,5].

Conclusion

We first validated the feasibility of the ED system for digestate treatment and thoroughly investigated the key challenges of its application, including long-term stability and high energy consumption. This research would advance the practical application of ED technology for large-scale digestate treatment.

Acknowledgements

This work is supported by Gas Networks Ireland – Science Foundation Ireland joint fund (No.12/RC/2302_P2), and Natural Science and Foundation of China (Ref: 51578205; Ref: 51728801).

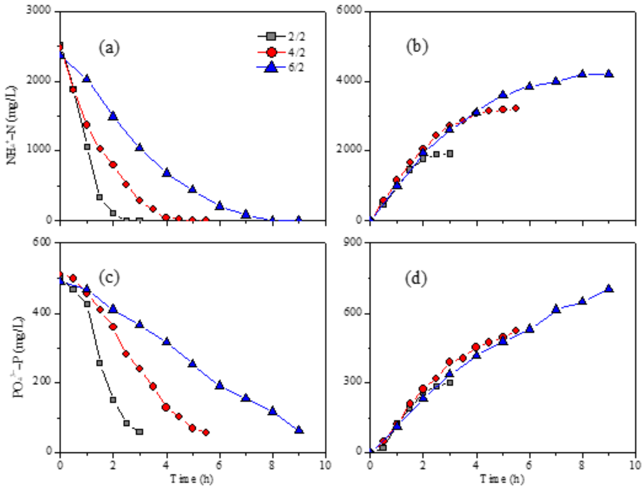

Fig. 1. Variation of NH_4^+-N and PO_4^{3-}-P at different volumetric ratios during EDR: (a) NH_4^+-N in the feed solution; (b) NH_4^+-N in the product solution; (c) PO_4^{3-}-P in the feed solution; and (d) PO_4^{3-}-P in the product solution.

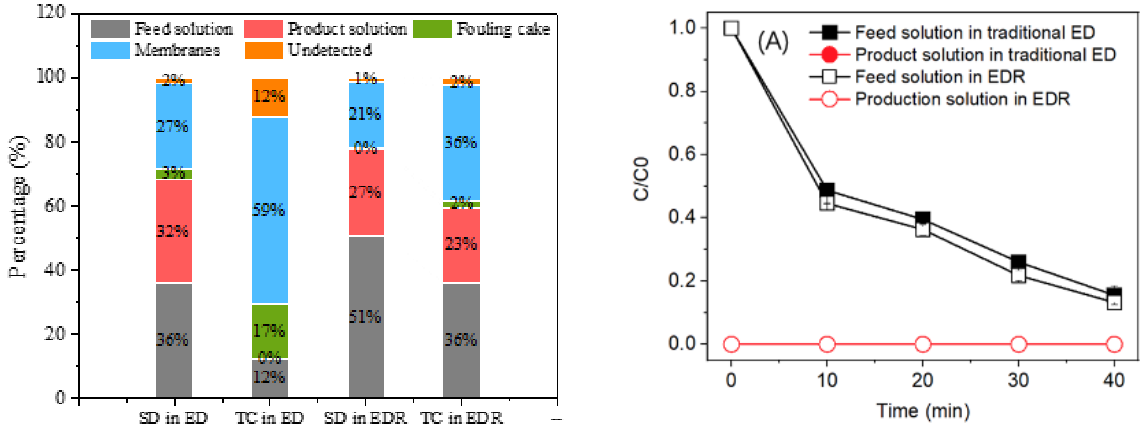

Fig.2. Distribution of SD and TC after the anode-ED and anode-EDR processes (a) and removal of 17β-estradiol in anode-ED and anode-EDR process.

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