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Gas-diffusion-electrode based direct electro-stripping system for gaseous ammonia recovery from livestock wastewater

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A B S T R A C T

Livestock wastewater (LW) typically contains a substantial amount of NH_4^+ that can potentially be recovered and used in fertilizers or chemicals. In an attempt to recover NH_4^+ from LW, a novel electrochemical approach using a gas diffusion electrode (GDE) was developed and its efficacy was demonstrated in this study. The GDE-based electrochemical device, when operated at an air-flow rate of 20 mL/min, was free of back-diffusion flux, which is a fatal drawback of any membrane-based NH_4^+ separation approach. Continuous operation resulted in a nitrogen flux of 890 g N/m^{2}d with synthetic LW and 770 g N/m^{2}d with real LW at a current density of 10 mA/cm^2. The electrochemical energy input was 7.42 kWh/kg N with synthetic LW and 9.44 kWh/kg N with real LW. Compared with the traditional stripping method, the GDE-based electrochemical system has a certain potential to be competitive, in terms of energy consumption. For instance, a rough-cost estimate based only on operating costs regarding chemical usage, air blowing, and water pumping revealed that the system consumed 13.44 kWh/kg N, whereas the conventional stripper required 27.6 kWh/kg N. This analysis showed that an electrochemical approach such as our GDE-based method can recover NH_3, (particularly in gaseous form) from LW. In addition, with the future development of a smart operation method, as proposed and demonstrated in this study, the cost-effective implementation of a GDE-based method is feasible.

1. Introduction

Ammonia (NH_3), an essential nutrient for biological metabolism, is also considered a future carbon-free energy carrier. It is produced primarily through the energy-intensive Haber-Bosch process (35–50 MJ/kg N), which consumes as much as 2% of the world's total energy and is responsible for approximately 1.6% of global CO_2 emissions (Hou et al., 2018; Xie et al., 2016). The major commercial application of total ammonia nitrogen (TAN) is as a nitrogen-based fertilizer, and approximately 30% of applied fertilizer is eventually transported into a wastewater stream (Bartels, 2008; Verstraete et al., 2009). Such dramatic TAN runoff not only adversely affects the bioactivity of microorganisms involved in anaerobic digestion but also causes eutrophication and other environmental problems (Chen et al., 2008; Hou et al., 2018). Mainstream technologies for treating TAN rely, ultimately, on converting it to N_2. From a treatment standpoint, these methods are highly effective and mature; however, from the perspective of resource recovery, these technologies are inadequate. Furthermore, they do not address the potentially fatal issue of releasing N_2O, a greenhouse gas.

Recovery, instead of removal, is a better and necessary approach. It can be and has been carried out using physical and chemical approaches such as NH_3 stripping, ion exchange, and precipitation (Booker et al., 1999; Deng et al., 2014; Uludag-Demirer et al., 2008; Yuan et al., 2016). These methods, however, are associated with critical caveats such as large energy requirements and high costs associated with the consumption or regeneration of chemicals. Ion exchange, though selective in a general sense, can also absorb unwanted cations present in wastewater, resulting in effluents that do not meet product quality standards for downstream applications (Hou et al., 2018). Precipitation products, especially struvite, often require the addition of other components, which themselves are also pollutants (Yuan et al., 2016). NH_3 stripping is a superior approach in many aspects, yet lacks economic competitiveness: blowing heated air and supplying alkaline chemicals are expensive operations (Deng et al., 2016).

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