Electrochemical cell design and recovery (RRS12)

Energy and resource recovery

Re-Inventing the Nation's Urban Water Infrastructure (ReNUWIt)

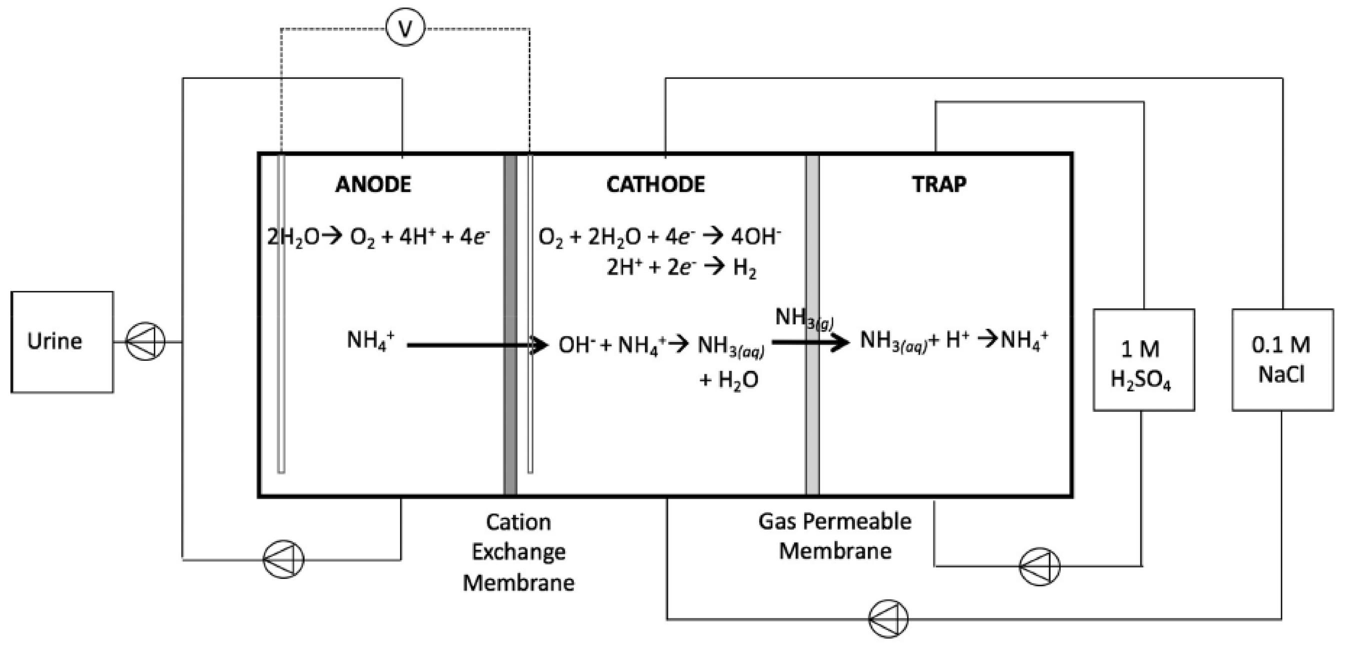
Naomi Ray, Valmik Lakhlani, Will Tarpeh
Stanford University

Background

Too much nitrogen in wastewater effluent can lead to excessive growth of plants and algae which causes oxygen depletion (Tarpeh, 2018). This project was inspired by Dr. Will Tarpeh's Electrochemical Stripping to Recover Nitrogen from Source-Separated Urine project, as seen below. The electrochemical cell design was originally an anode, cathode, and acid trap separated by a cation exchange membrane and a gas diffusion membrane.

Urine was used as the reagent because of its low volume but high concentration of nitrogen. The nitrogen captured from the electrochemical process within the anode and cathode chambers is in the form of ammonia, which is then converted into ammonium salts, like ammonium sulfate within the trap, which are commonly used in fertilizers. Electrochemical stripping improves on conventional ammonia stripping with added benefits like high nitrogen recovery and efficiency.

Our task was to consider how to improve the cell design for the tasks at hand.



Approach

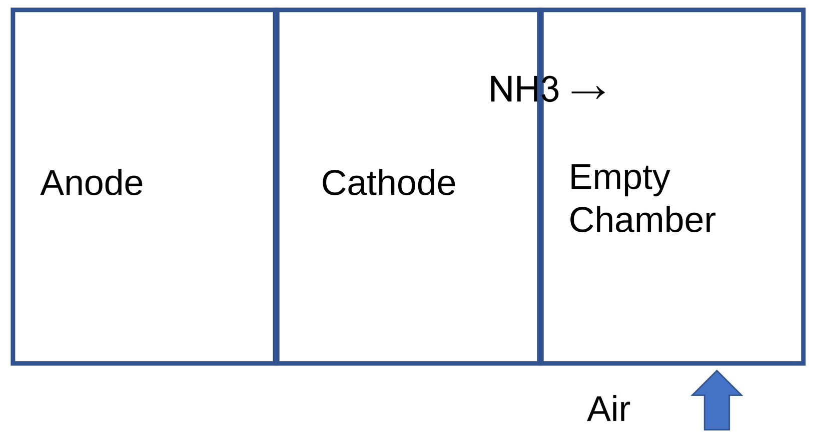
This project was divided into 2 parts:

1) Cell Fabrication and Design to solve several problems

- Potential fluid leakage
- Membrane fitting and replacement
- Potential leaks of gas

2) Designing methods for capturing ammonia

- instead of using the 3rd chamber as an acid trap, the NH_3 from the cathode enters this chamber and is extracted with an air stream. Then, the air and NH_3 is then passed through to to an acid solution to form ammonium sulfate fertilizer.



Advantages(compared to the acid trap design)**:**

- low cost
- high yield

We aim to completely strip the ammonia from the chamber at a minimum air flow rate. by using existing countercurrent design equations to calculate the minimum air to water ratio for appreciable nitrogen recovery for fertilizers.

Assumptions:

- The effluent gas from the stripper is in equilibrium with the incoming NH_3.
- Assume influent gas from cathode is 100% NH_3 with minimum moisture because the gas permeable membrane is hydrophobic and so we assume that it has a really high Henry's constant.
- Operating at room temperature.

$$S_{Gas} = k_h \times P_{Gas}$$

Results

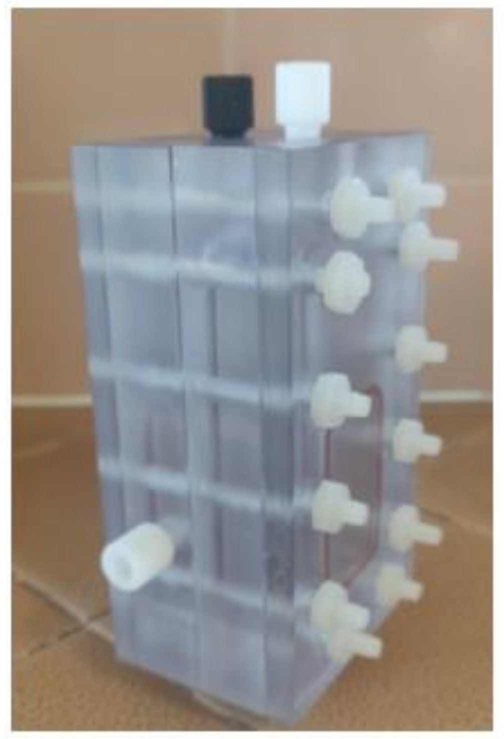
1) Final Cell Design

Solutions:

- PCFTE O-rings placed between the gaps/joints between chambers for preventing fluid leakage between cell chambers. The material has a very low porosity for low gas leakage of small molecules like hydrogen gas, but it also has an aversion to moisture.
- Designed an easier membrane fitting and removal through a slot system similar to a drawer. But a drawback is that the sliding membrane piece would cover the internal O-rings reducing the grip between the different pieces.

Original Cell

Final cell



Gaps Between Chambers

2) Air Stripping

The design equation used for the minimum ratio of the volumetric flow rate for air and ammonia is:

$$\left[\frac{Q_a}{Q}\right] = \left[\frac{C_o - C}{H \times C_0}\right]$$

where C_0 is incoming concentration of ammonia and C_c is target outlet concentration, H is Henry's constant (at 20 ℃ equals 0.0136).

We use the target concentration to be the nominal concentration of nitrogen in conventional fertiliser (200 mg N/L) and the input to be maximum of the pre measured range of 1000 mg N/L transported across the gas permeable membrane from the experiment conducted in the paper.

These values result in a ratio of **73.2**, which indicates that the air flow rate needs to be *at least* 73.2 times faster to result in the desired rate.

Using the diffusivity of ammonia in air, the estimated the mass flow rate of ammonia produced by the membrane (g/s) is solved for and then used along with the minimum factor, and the density of ammonia at rtp to calculate the minimum air flow to result in approximately **3.25×10^{-3} m³/s**

Though this method gives us an idea of the orders of magnitude of the expected flow rate, we do anticipate that a higher air flow rate will increase ammonia removal efficiency - up to a certain point. Beyond this point, the air is flowing too fast to appreciably collect enough ammonia as it enters the chamber and can lead to an expensive process.

Citation: Liu, B. , Giannis, A. , Zhang, J. , Chang, V. W. and Wang, J. (2015), Air stripping process for ammonia recovery from source‐separated urine: modeling and optimization. J. Chem. Technol. Biotechnol., 90: 2208-2217. doi:10.1002/jctb.4535

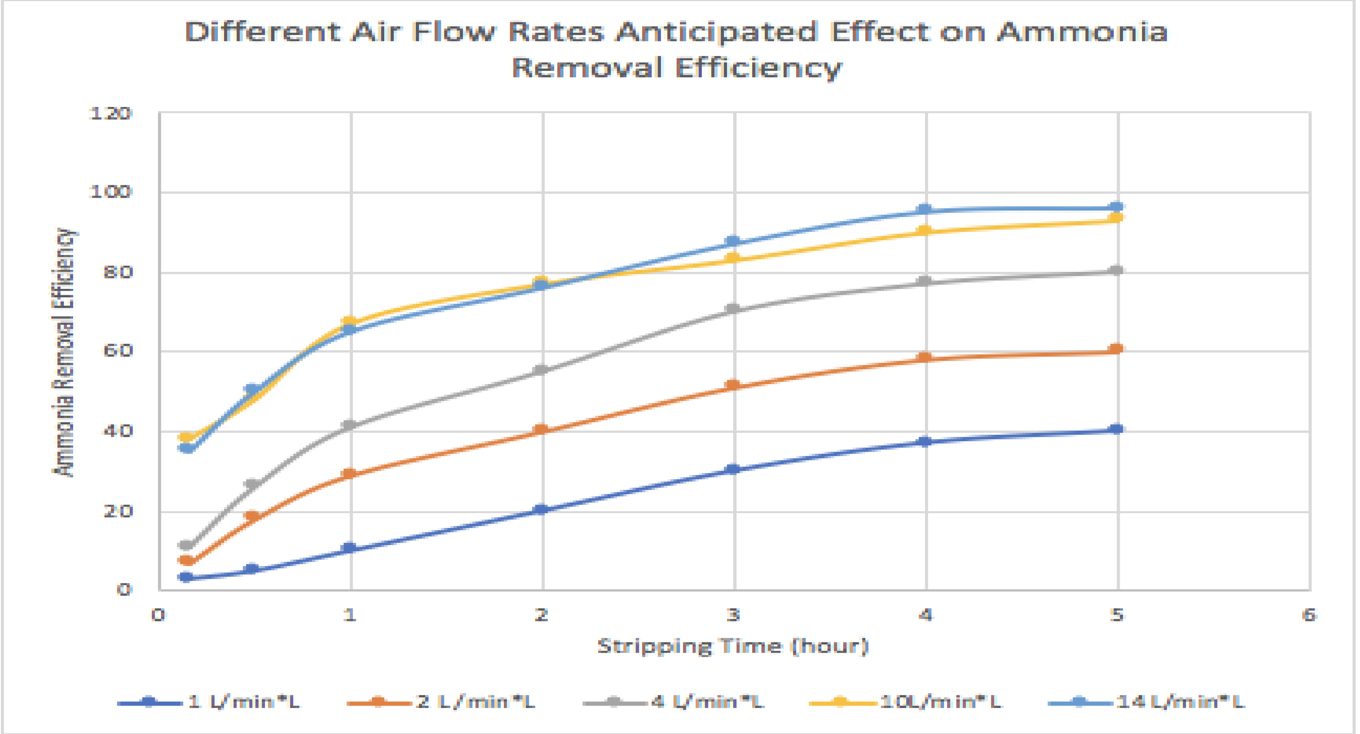
Conclusions

1) Cell Design

- Cell design much improved with the O-rings. Fluid leakage has stopped.

2) Air Stripping

- Estimation method is not accurate due to the large number of assumptions made of the concentration and quality of our flows and the counterflow design calculations. But it does give a fair estimate based on the orders of magnitude expected.
- Air flow rate accuracy is the main method of maintaining a balance within the process, make it more competitive in terms of efficiency and cost than the acid trap
- Other conventional methods to increase efficiency of the process can be adopted to reduce the stringent air flow requirements, such as: influencing temperature and introducing a packed bed system within the chamber to improve the contact time within a fixed cell volume and provide a high surface area for the exchange



Next Steps

1) Cell Design

- Implement the cell to be flexible based on any variable design such that it can act as a basis for any variation.
- Another factor to investigate would be the time saving sliding membrane system that would combat the issues faced.

2) Air Stripping

- Practically experiment air stripping in the third chamber to remove the ammonia entering from the cathode.
  - Incorporate experimental data to support theoretical calculations of operating conditions to improve our model.
  - Re-calculate the air flow requirements based on a more realistic cross flow system/design equation.
  - Use a boundary layer configuration against a vertical flat plate to try to test if it can realistically determine the actual flow rate required or if one of the earlier methods would be of a significant accuracy.
- Find the optimal air flow rate to produce enough nitrogen for fertilizers and disinfectants by testing varying flow rates.
  - Measure the energy used and compare costs to the 3 chamber cell.

Acknowledgements

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Citation: Electrochemical Stripping to Recover Nitrogen from Source-Separated Urine
William A. Tarpeh, James M. Barazesh, Tzahi Y. Cath, and Kara L. Nelson
Environmental Science & Technology 2018 *52* (3), 1453-1460
DOI: 10.1021/acs.est.7b05488

Research Scholar Contact Information

Naomi Ray | naomiray@stanford.edu

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