



Towards enhanced nutrient recovery, biogas production and upgrading through AD and BES integration

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Abstract: The production of fertilizers with macronutrients phosphorus (P), potassium (K) and nitrogen (N) is unsustainable and increasingly expensive due to the depletion of finite mineral deposits (P, K) and high energy consumption (N). Therefore, nutrient removal and recovery (NRR) is becoming increasingly important. In conventional wastewater treatment, the produced sludge is often treated in anaerobic digesters (AD), yet most macronutrients end up in the digestate – offering opportunities for NRR. Existing recovery methods are typically energy-intensive or require the addition of chemicals, whereas recovery using bio-electrochemical systems (BES) offers a low-energy, chemical-free alternative. In addition to NRR, integration of AD and BES technologies reduces the ammonia load to AD, promoting biogas production, and the produced biogas can be upgraded e.g. through the injection of H₂ produced in the BES into the AD.

Keywords: nutrient recovery; reject water; bio-electroconcentration

Session 9: Nutrient removal/recovery linked to AD

Introduction

Macronutrients P, N and K are extensively used in agricultural fertilizers. Issues related to fertilizer production include the use of finite resources, high energetic demand and environmental pollution (Sutton et al., 2013). However, a large amount of nutrients used in agriculture end up in human excreta after food consumption (Jönsson & Vinnerås, 2013), making domestic wastewaters an interesting target for NRR. In a contemporary municipal wastewater treatment plant (WWTP), N is predominantly present in the reject water resulting from the dewatering of anaerobically-digested sewage sludge, whereas most of the P remains in the solid fraction of the sludge (Ek et al., 2006).

Current NRR methods such as N-stripping are energy-intensive and require the addition of chemicals (Siegrist et al., 2013). Bioelectrochemical systems (BES), in which current generated from wastewater by bacteria can be used for NRR in a configuration known as bio-electroconcentration (see Fig. 1.1), offer a more sustainable, low-energy and chemical-free alternative. Furthermore, in BESs, pH differences form naturally, and can be used for ammonia stripping (Desloover et al., 2012). Removing N from reject water before recirculating it back to the WWTP reduces the ammonia load of the AD, decreasing process inhibition, and injecting H₂ produced at the BES to the AD can help further upgrade the biogas (Luo et al., 2012).

Materials and Methods

Two lab-scale 3-chamber bio-electroconcentration cells (Figure 1.1) were used to study the electrically-driven up-concentration of NH₄⁺ and other ions into the concentrate chamber with both synthetic and real reject water obtained from a lab-scale thermophilic AD reactor (see properties in Table 1.1). The anode was poised at a constant potential of 0.0 V vs. standard hydrogen electrode (SHE). Electroactive microorganisms were enriched on the anode (graphite granules) to act as a biocatalyst, simultaneously decomposing organic matter in the reject water and reducing the energy demand of the process.

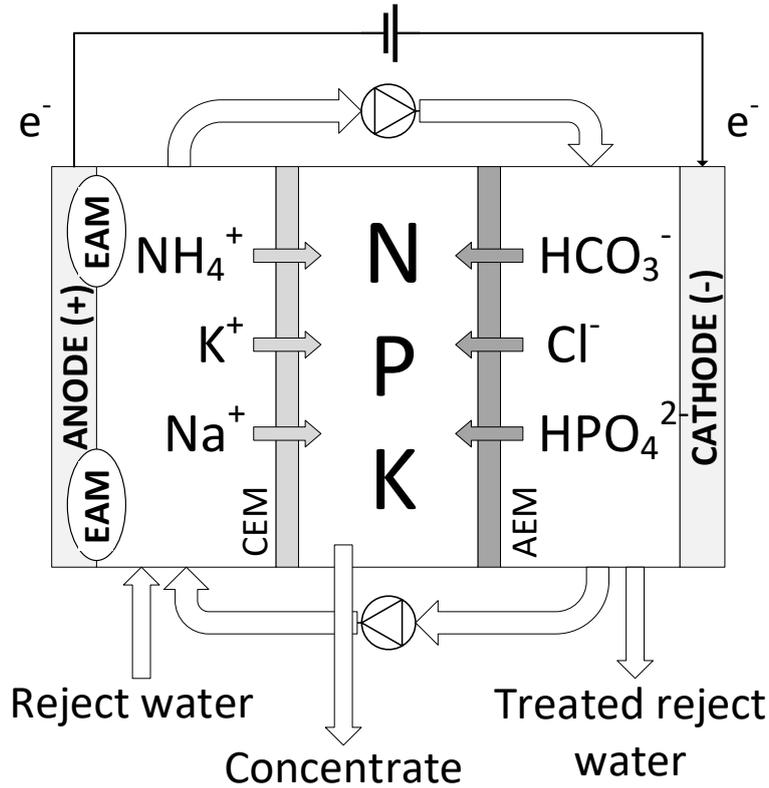


Figure 1.1 Operating principle of the 3-chamber bio-electroconcentration cell (Ledezma et al., 2017). EAM: electroactive microorganisms; CEM: cation-exchange membrane; AEM: anion-exchange membrane.

Table 1.1 Physicochemical properties of the real reject water from a lab-scale thermophilic AD reactor.

	Parameter	Unit	Value
	pH	-	8.26
	EC	mS cm ⁻¹	14.34
	sCOD	mg L ⁻¹	9508
VFAs	Acetate	mg L ⁻¹	110
	Propionate	mg L ⁻¹	500
	Butyrate	mg L ⁻¹	23
	Isobutyrate	mg L ⁻¹	25
	Dissolved inorganic carbon	mg L ⁻¹	1415
	Alkalinity	mg HCO ₃ ⁻ L ⁻¹	9357
	NH ₄ ⁺ -N	mg L ⁻¹	1170
Cations	K ⁺	mg L ⁻¹	246
	Na ⁺	mg L ⁻¹	84
	Mg ²⁺	mg L ⁻¹	11
	Ca ²⁺	mg L ⁻¹	14
Anions	PO ₄ ³⁻	mg L ⁻¹	2
	SO ₄ ²⁻	mg L ⁻¹	14
	Cl ⁻	mg L ⁻¹	85

A synthetic reject water with a pH of 8.0±0.1 and electrical conductivity (EC) of 7.1±1.2 mS cm⁻¹ was formulated to imitate the real reject water as closely as possible. The effect of hydraulic retention time (HRT) on the up-concentration, total recovery and recovery rate of NH₄⁺-N were studied with the synthetic reject water. After that, an HRT_{cell} of 8 h was chosen for up-concentration experiments with the real reject water.

Results and Conclusions

The experiments with synthetic reject water showed that decreasing the HRT led to increased up-concentration and recovery rate but reduced total recovery of $\text{NH}_4^+\text{-N}$ (Figure 1.2). With an up-concentration factor of 7.4 ± 0.5 , total recovery of $55.5 \pm 2.9\%$ and recovery rate of $965 \pm 39 \text{ g m}^{-3} \text{ d}^{-1}$, an HRT of 8 h was selected for the initial tests with the real reject water.

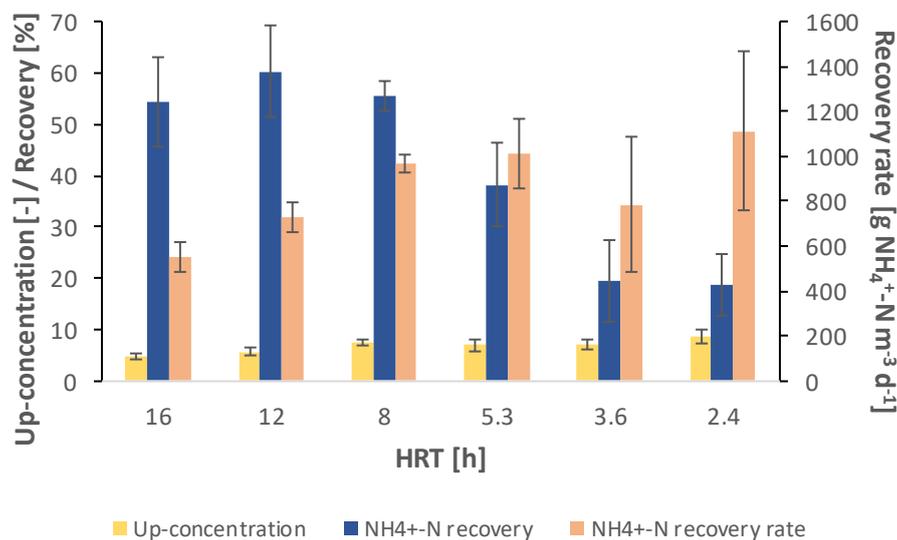


Figure 1.2 Effect of HRT on the up-concentration, total recovery and recovery rate of $\text{NH}_4^+\text{-N}$.

Compared to the synthetic reject water with the same HRT, the obtained current density increased from 3.7 ± 0.4 to a maximum of 8.99 A m^{-2} , total $\text{NH}_4^+\text{-N}$ recovery from 55.5 ± 2.9 to 62.1% and $\text{NH}_4^+\text{-N}$ recovery rate from 965 ± 39 to $1963 \text{ g m}^{-3} \text{ d}^{-1}$ when using real reject water (Table 1.2). This was likely due to the higher organic matter content (as chemical oxygen demand, COD) and higher conductivity of the real reject water.

Table 1.2 Comparison of $\text{NH}_4^+\text{-N}$ recovery results in the 3-chamber bio-electroconcentration cell with different wastewaters.

	Feed	$c(\text{NH}_4^+\text{-N})$ in the feed (mg L^{-1})	J (A m^{-2})	$\text{NH}_4^+\text{-N}$			Reference
				Up-concen- tration	Recovery (%)	Recovery rate (g m^{-3} d^{-1})	
UGold	Urine, synt.	5880	29.3 ± 2.3	4.45^a	49.5 ± 1.8	7180	Ledezma et al., 2017
SGold	Sewage, synt.	65	1.9 ± 0.0	27.9 ± 0.4	22.7 ± 0.8	43.3 ± 1.5	Monetti et al., 2018
	Sewage, real	63	1.87 ± 0.1	20.1 ± 1.9	12.0 ± 1.4	24 ± 2.9	
RGold	Reject water, synt.	1170	3.7 ± 0.4	7.4 ± 0.5	55.5 ± 2.9	965 ± 39	This study
	Reject water, real.	2044	8.99^a	6.8^a	62.1^a	1963^a	

^aMaximum value obtained

The results obtained here are compared with other wastewater streams under the same reactor configuration in Table 1.2. As could be expected, the highest current densities and $\text{NH}_4^+\text{-N}$ recovery rates were obtained with synthetic urine given its higher conductivity and initial $\text{NH}_4^+\text{-N}$ concentration (Ledezma et al., 2017). However, the total $\text{NH}_4^+\text{-N}$ recovery is in the same range with both synthetic urine and synthetic and real reject water.

In order to enhance N recovery from reject water further, a stripping unit is currently being integrated to the cathode of the 3-chamber bio-electroconcentration cell. This way, the remaining NH_4^+ that does not migrate to the concentration chamber from the anode will be circulated to the

cathode, where the increased pH of the catholyte will deprotonate it to NH_3 . This NH_3 can be stripped with the H_2 produced at the cathode. The planned AD and BES integration is presented in Figure 1.3. In addition to increased NH_4^+ -N recovery, removal of N from the reject water reduces the N-return load to the WWTP and thus to the AD, enhancing biogas production. Furthermore, the hydrogen produced at the cathode of the BES can be injected into the AD to further upgrade the biogas.

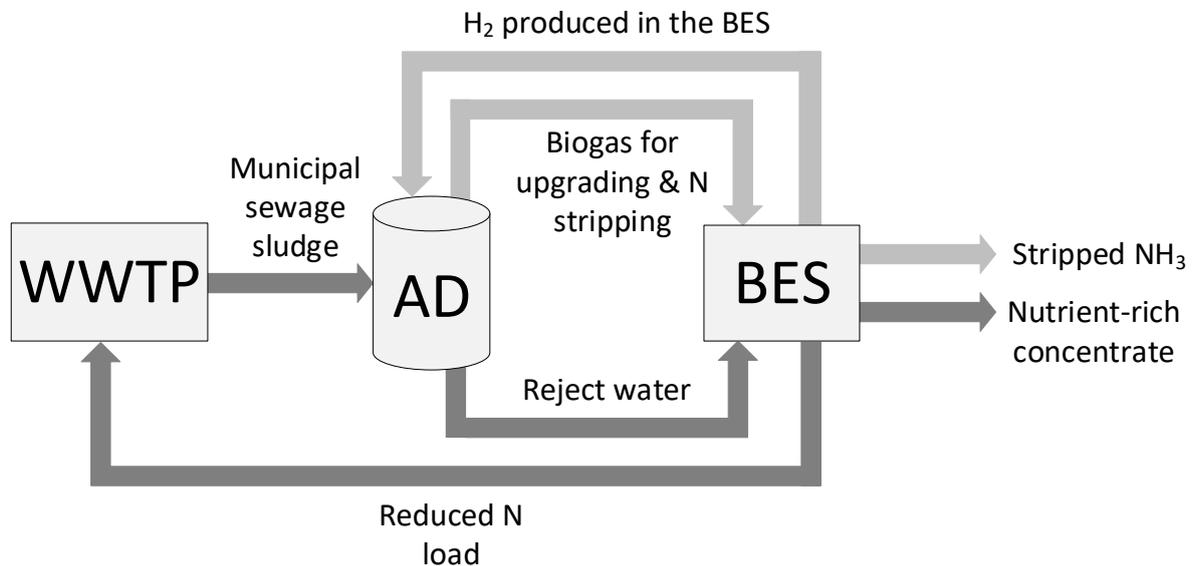


Figure 1.3 Schematic principle of the AD and BES integration. Liquid flows are marked with darker grey and gas flows with lighter grey arrows.

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