(Bio)electrochemical nitrogen recovery at full WWTP scale: Modelling and techno-economic assessment

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ABSTRACT

At conventional wastewater treatment plants (WWTPs), reject waters originating from the dewatering of anaerobically digested sewage sludge are the nitrogen-richest streams. Nitrogen removal and recovery (NRR) from reject waters can be considered beneficial as 1) nitrogen can be recovered in a reusable form; and 2) the nitrogen load to the activated sludge process can be reduced, thereby decreasing its energetic and chemical demands. (Bio)electrochemical systems have been extensively studied for nitrogen recovery in laboratory-scale but not yet implemented in full scale.

In this study, the potential effects of integrated (bio)electrochemical nitrogen removal from reject water on a full WWTP scale and its feasibility were assessed through modelling and techno-economic analysis. Experimental data from laboratory-scale tests with three-chamber (bio)electroconcentration ((B)EC) cells used for nitrogen recovery from reject waters (Koskue et al. 2021a, 2021b) were used to construct a semi-empirical MATLAB/Simulink NRR model block. The NRR model was integrated into the existing Benchmark Simulation Model No. 2 (BSM2; Gernaey et al. 2014) representing a generalised WWTP. Dynamic simulations were used to evaluate the effect of the NRR unit on the effluent quality and OPEX of the WWTP and to compare it to the BSM2 performance without the NRR unit. The techno-economic analysis was focused on identified key OPEX, namely the electric energy used for aeration and the NRR unit, external carbon addition and the revenue for the recovered nitrogen, as well as the CAPEX of the NRR unit. Net present value (NPV), which discounts the expected future cashflows to their current value, was selected as the economical profitability indicator.

In all the scenarios with the NRR unit, the overall WWTP effluent quality index was improved by 4–11%, while violations of the effluent limit for total nitrogen (18 g m^{-3}) were completely prevented. At the same time, the aeration requirements were reduced by 7–19% and carbon additions by 24–71% compared to the control without the NRR unit. The additional electrical energy consumed by the NRR unit increased the total OPEX index by ≥ 18%, but the revenue assumed for the recovered nitrogen (20 EUR kg_N^{-1}) was sufficient to make the BEC – at realistically low current densities of 1 and 5 A m^{-2} – economically attractive compared with the control scenario where no NRR unit was used. At best, using the lowest current density of 1 A m^{-2}, a positive NPV of 0.1 EUR m^{-3} wastewater treated suggested net profit from wastewater treatment, when compared to the NPV cost of -9.5 EUR m^{-3} in the control scenario without NRR.

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References:

Gernaey, K.V., Jeppsson, U., Vanrolleghem, P.A., Copp, J.B. (2014). Benchmarking of control strategies for wastewater treatment plants. *Scientific and Technical Report No. 23*, IWA Publishing.
Koskue, V., Freguia, S., Ledezma, P., Kokko, M. (2021a). Efficient nitrogen removal and recovery from real digested sewage sludge reject water through electroconcentration. *Journal of Environmental Chemical Engineering*, 9 (5), 106286.
Koskue, V., Rinta-Kanto, J.M., Freguia, S., Ledezma, P., Kokko, M. (2021b). Optimising nitrogen recovery from reject water in a 3-chamber bioelectroconcentration cell. *Separation and Purification Technology*, 264, 118428.