Sustainable nitrogen removal from industrial textile wastewater by decentralized autotrophic biological process

G. Bellandi*, S. Visigalli*, A. Turolla*, M. Bellucci*, G. Menin*, R. Di Cosmo*, A. Molteni*, G. Adungah*, M. Bargna, G. Bergna**, R. Canziani***

* Politecnico di Milano, DICA - Environmental Section, Milano, Italy, roberto.canziani@polimi.it
** Lariana Depur, Fino Mornasco, Italy

Abstract: Autotrophic nitrogen removal emerged as a promising solution for treating nitrogen-rich wastewater. In LIFE DeNTreat project, a single-stage partial nitritation/anammox process was applied as a decentralized treatment to industrial wastewater from digital textile printing. In addition to reduction of total nitrogen concentration from about 200 to 50 mgN/L, experimental data combined with modelling demonstrated relevant benefits with respect to the current scenario, in which industrial wastewater is treated with municipal wastewater in a centralized wastewater treatment plant (WWTP): reductions on energy consumption (-15%), greenhouse gas (N_2O) emissions (50 times lower), elimination of external carbon source at existing WWTP, sludge production (-25%).

Keywords: Decentralized wastewater treatment; industrial wastewater; nutrient removal.

Introduction

The recent massive spread of digital textile printing worldwide (GIA, 2018) has the significant disadvantage of producing rinsing baths containing high concentrations of organic compounds (dyes and additives), organic nitrogen (urea) and ammonium. In Como textile district, in Italy, centralized wastewater treatment plants (WWTPs) receive process water from industries through the public sewage system, also collecting municipal wastewater. The massive use of urea in digital printing causes a significant increase in total nitrogen content (from 150 to 600 mgN/L) in industrial wastewater and an overall imbalance in the ratio between COD and N in the sewage. Therefore, two problems occurred: (i) the industrial wastewater discharge into the sewer, since limits for total nitrogen are set at 30 mgN/L with local derogations up to 100 mgN/L, (ii) the effective wastewater treatment by existing conventional WWTPs.

In the past 20 years, autotrophic nitrogen removal using anammox-based biomass processes emerged as a sustainable alternative (Hu et al., 2013). These processes were successfully applied to industrial wastewater (Lackner et al., 2014), although their stabilization is complicated by the need to maintain low COD/N ratios and by inhibition phenomena resulting from wastewater toxicity (Li et al., 2018).

The EU LIFE DeNTreat project (https://www.life-dentreat.eu/) aims to apply a process based on anammox biomass (combined single-stage process of partial nitritation and anammox, PN/anammox) for the decentralized treatment of wastewater from digital textile printing in the Como textile district. The present work is focused on benefits generated on wastewater treatment impacts. The autotrophic biological process was implemented at lab-scale, while monitoring data from the PN/anammox reactor and the existing centralized WWTP were used to perform scenario analyses.

Materials and methods

The lab-scale reactor, that is described in Bellandi et al. (2019), is a 2-L sequencing batch reactor (SBR), inoculated with biomass from Paques (Balk, The Netherlands). During the start-up period, the reactor was fed with synthetic wastewater and then the ratio of textile wastewater was progressively increased. The centralized WWTP has a biological phase based on sequential denitrification-nitrification, in which the first step is carried out by adding external organic carbon in form of glycerine and acetate, with a flowrate of 20 L/h and 100 L/h, respectively.

Two scenarios were simulated: (i) scenario 0 (business as usual), the existing situation in which the nitrogen load at the conventional WWTP is about 80.000 kgN/year, (ii) scenario 1, the combined application of PN/anammox process as preliminary treatment in the textile factory (flowrate: about 1.000 m^3/day, nitrogen load: about 60.000 kgN/year) and existing conventional WWTP. Experimental data from lab-scale reactor and centralized WWTP monitoring were used as model inputs. Key performance indicators adopted in scenario analyses were energy consumption, greenhouse gas emissions, reagent consumption and sludge production.

Results and discussion

As shown in Table 1, wastewater from industry equalization tank was characterized by relevant nitrogen content, already partially ammonified (around 75%), and a ratio between biodegradable fraction of COD and total nitrogen ratio around 2.

Experimental data from lab-scale reactor are reported in Figure 1, highlighting good nitrogen removal efficiency at steady-state, with effluent concentrations of total nitrogen of about 50 mgN/L, thus compliant with sewage discharge under derogation. The start-up phase confirmed the importance of an acclimation period for reaching steady-state conditions. After switching to textile wastewater, a significant reduction in bacterial activity was observed, leading to quasi-stable condition until day 115, when a probe failure caused the pH to be operated at sub-optimal values. Best efficiencies were obtained in the second part of the experimental campaign, up to 70%, although it is important to highlight the strong process variability mostly due to operational technical instabilities. Biofilm profile in granules along experimental campaign was simulated and predictions were confirmed by microbiological analysis.

Scenario analyses were used to compute key performance indicators for each alternative. As for energy consumption, models predicted a reduction from 1,026,000 to 874,500 kWh/year passing from scenario 0 to scenario 1, indicating a 15% decrease in case that the totality of wastewater from case-study textile industry is treated, considering that it is characterized by significant dimensions within Como textile district. Considering greenhouse gasN_2O emissions, given the limited agreement on PN/anammox literature, emissions were measured both in lab-scale reactor and at full scale centralized plant. An emission factor (EF) of about 0.01% ($N_2O_{emitted}/TN_{removed}$) was observed at lab-scale, while 0.55% was measured at the centralized plant. Model predictions estimated a reduction in EF from 0.24% (±0.25%) to 0.11% (±0.25%), when switching from scenario 0 to scenario 1 in good agreement with measured data (already with default N_2O parameter). As for reagent consumption, the implementation of scenario 1 would result in the reduction of the nitrogen load entering the plant and in the consequent modification of the COD/N ratio up to values of 12, resulting in avoidance of external carbon dosage and in economic saving of about 70,000 €/year. Finally, the quantity of sludge varied from 558 kgTSS/day for scenario 0 to 418 kgTSS/day for scenario 1.

In summary, the key performance indicators estimated a substantial modification of the impacts related to wastewater treatment in the two scenarios, indicating the decentralized treatment of nitrogen-rich industrial effluents as an effective solution.

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Table 1 Characteristics of different wastewater (WW) samples from textile industry.

	WW1 [mg/L]	WW2 [mg/L]	WW3 [mg/L]	WW4 [mg/L]
COD	628	676	395	728
NH_4-N	178	168	33.4	17.5
NO_3-N	0	0.95	4.9	1.34
NO_2-N	0	0	0.9	0
Total Nitrogen	238	216	508	728

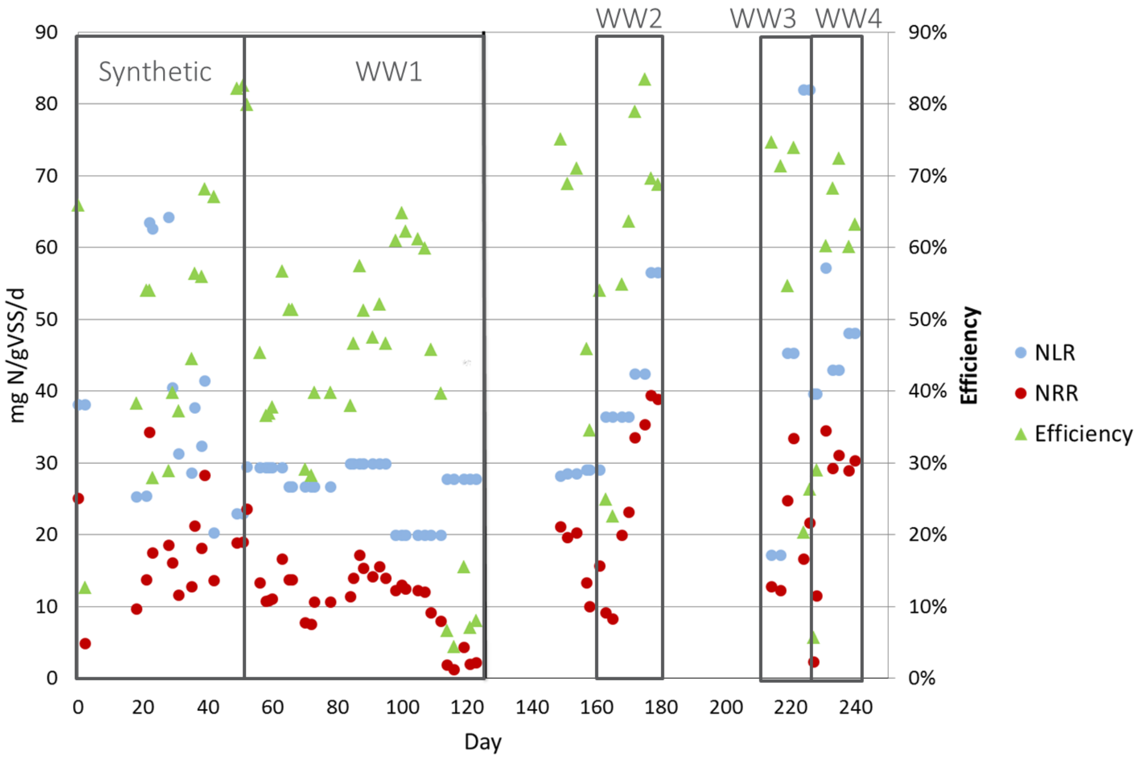

Figure 1 Main nitrogen indicators, namely nitrogen loading rate (NLR), nitrogen removal rate (NRR) and nitrogen removal efficiency, in lab-scale PN/anammox reactor during the experimental campaign with the synthetic medium and the different industrial wastewaters (WW).