Sludge management and greenhouse gas (GHG) emissions at a wastewater treatment plant (WWTP): getting some clues on a possible nexus

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The principal tasks of a wastewater treatment plant (WWTP) are, on the one hand, to treat wastewater to make it compliant with the legal limits for discharge in natural receiving water bodies and, on the other hand, to stabilize and reduce the volume of sludge separated from the processes of wastewater treatment. Sewage sludge is made of primary sludge (PS), that is separated through a physical process in primary settlers, and waste activated sludge (WAS), that is generated from the biological treatment of wastewater. The stabilization process of sludge is commonly performed through anaerobic digestion (AD), the aim of which is not only reducing the volume of sludge and making it stable, but primarily producing an amount of biogas sufficient to self-sustain the AD process and possibly supplying the WWTP and the close users with energy in the form of hot water and electricity. In this context, the limited biodegradability of WAS inhibits the first step of AD, that is the hydrolysis, with a consequent reduction of methane production and volatile solid (VS) consumption. Various pre-treatments (mechanical, thermal, chemical, biological or a combination of some of these) have been developed to cope with this problem, thus promoting the hydrolysis rate and the overall performance of the AD process.

Because WAS contains on average 12% by weight of nitrogen, the application of pre-treatments to WAS increases the amount of nitrogen available for AD. The effects of this increase are a possible inhibition of the AD process and an enrichment of ammonia nitrogen, that includes both free ammonia (NH_3) and ammonium ion (NH_4^+), of the digestate. For what concerns the first aspect, both NH_3 and NH_4^+ have been recognized to be concurrent inhibitors of the methanogenic activity, even the emphasis has usually been on NH_3, because it was considered the most inhibitory form (Rajagopal et al., 2013). For what concerns the second aspect, it must be taken into account that digestate, after AD, is subjected to a post-thickening phase, where the solid phase is partially dewatered and the separated liquid phase is recirculated to the water line for a further treatment. In the case of pre-treatment application, the separated liquid phase contains nitrogen concentrations in the order of several thousand mg/l, thus affecting the performance of the biological processes for nitrogen removal in the water line. A test carried out in semi-continuous mode in a pilot-scale (300 L) digester on raw and thermo-alkali pretreated WAS collected from Castiglione Torinese WWTP (2 M equivalent inhabitants) demonstrated that the pre-treatment (90°C, NaOH 4% fed total solids) had increased the nitrogen content in the digestate by approximately 100%. In fact, amounts of NH_4^+ of approximately 30 and 60 g NH_4^+/ g VS fed to digester were found for the digestion of raw WAS and treated WAS respectively (Campo et al., 2019). These amounts of ammonium, after digestion, are inevitably recirculated to the water line.

The increase in the nitrogen load entering the WWTP and, specifically, the biological modules of the water line, is recognized to be responsible of several impacts on the WWTP itself and the surrounding environment. Studies carried out in the past years have made efforts to identify the role of the biological reactions involved in the traditional process of nitrogen removal (nitrification/denitrification) in nitrous oxide (N_2O) generation (Law et al., 2012; Ma et al., 2017). N_2O is recognized as a powerful atmospheric greenhouse gas (GHG) and cause of ozone layer depletion. In fact, despite of skepticisms from the anti-climate change movement, thanks to technological advances, climate change is no longer a scientific fiction. Several scientific studies have confirmed its long-term impacts through representative indicators such as temperature, greenhouse gases (GHGs) concentrations, extreme events, sea level changes and hydrological cycle (Edenhofer, 2015).

Furthermore, an increase in the nitrogen loads entering the water line can potentially lower the efficiency of the WWTP in nitrogen removal, thus leaving residual amounts of the nutrient in the effluents. Discharge of nutrient-containing effluents gets the quality of the receiving water body worse. Consequently, if waters of the receiving water body are used in irrigations systems for agricultural purposes, diffuse emissions of N_2O from fields have to be taken into account in a global GHG balance. Growing the worldwide concerns about GHG emissions and climate change, the issue of energy efficiency has been attracting attention (Friedrich et al., 2009). Wastewater treatment plants (WWTP) are demanding energy consumers. Considering the increasing number of WWTPs and establishment of the more stringent effluent quality requirements throughout the world, water agencies show a growing interest in the use of tools and methodologies to improve the energy efficiency of their facilities (Molinos-Senante et al., 2015).

This work considers the main Italian WWTP (2 M e.i.): in the past few years a number of studies have been carried out with the aim of enhancing the performances of its sludge line by using low temperature, alkali or hybrid pre-treatments. It was demonstrated that an improvement of the pre-thickening processes and the application of pre-treatments could improve the energy and economic balances of the WWTP, by saving auxiliary methane and increasing the amount of produced electricity. With this work we wants to analyze the effect of the application of pre-treatments on the cycle of nitrogen at the WWTP in terms of material balances, energy consumption, economic assessments, impacts on the surrounding environment due to the residual nitrogen in the WWTP effluents and impacts on the global system due to the emissions of N_2O into the atmosphere.

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