Microbial resource management for the mitigation of nitrous oxide emissions from the Partial Nitritation-Anammox process

Urban wastewater treatment plants are designed to remove pathogens and pollutants from wastewater in order to provide sanitation and to protect receiving water bodies from eutrophication. Reactive nitrogen, mainly in the form of ammonium, is one of the components in wastewater that is converted to dinitrogen gas during treatment. The Partial Nitritation-Anammox process (PNA) uses the capacity of autotrophic aerobic and anaerobic ammonia oxidizing bacteria (AOB and AnAOB) to perform this task. The process is mainly applied to treat ammonium-rich wastewater streams with low concentrations of organic carbon. Its advantages over conventional nitrogen removal technology include lower energy needs for aeration, no addition of organic carbon and reduced sludge production. However, emissions of the greenhouse gas nitrous oxide (N2O), that are commonly measured during process operation, have the potential to determine the CO2 footprint of PNA, thus off-setting its environmental benefits. Consequently, strategies to mitigate N2O emissions from PNA are needed. In the presented Ph.D. study a laboratory scale PNA model system was investigated to infer beneficial modes of process operation for high rate PNA with simultaneously low N2O emissions. Dynamics of N2O emission, production and consumption reactions were quantified to identify correlations between N2O and process parameters, a method to engineer the microbial community by aeration patterns was tested and a N2O mitigation strategy based on pH set-points was evaluated. The concept of Microbial Resource Management (MRM) was adopted to steer the fraction of AOB and AnAOB in bio-granules and to manipulate the activity of enzymes relevant for N2O metabolism. Both, microorganisms and enzymes were considered as microbial resources. The characterization of the system revealed that net N2O production in aerated phases primarily contributed to overall N2O emissions (80-100%). The remaining N2O was produced during non-aerated phases, leading to distinct N2O emission peaks at the onset of aerated phases. Net N2O production rates in aerated phases were positively related with the specific ammonia removal rate, while during non-aerated phases net N2O production rates were positively correlated with the nitrite concentration (NO2-). Operation of PNA at reduced specific ammonia removal rates is, therefore, a feasible strategy to mitigate N2O emissions. However, when high ammonium removal rates shall be maintained, an increased NO2- sink capacity by a relatively larger fraction of AnAOB has the potential to reduce N2O production. Changes of the intermittent aeration regime were applied to engineer the microbial community. Indeed, longer aerated phases were feasible to increase the size of bio-granules by approx. two-fold, which resulted in an increase of the AnAOB/AOB ratio from 0.4 up to 1.4. However, an effect of median granule size and granule size distribution on process performance was not detectable, since periodic non-aerated phases in intermittently aerated PNA had stronger regulating effects on NO2- accumulation, than the granule size distribution had. Consequently, the granule size distribution was less relevant for stable process performance in intermittently aerated PNA systems, than for continuously aerated systems. Net N2O production is the difference between N2O production and consumption. Therefore, increased N2O consumption rates reduce net N2O production, also when production is not altered. A comprehensive review, synthesizing current knowledge on the effect of pH on enzymes involved in nitrogen conversions, suggested a N2O mitigation strategy based on pH set-points. Indeed, pH exerted a strong effect on N2O emissions, when emission factors (% N2O-Nproduced/NH4+-Nremoved) increased with pH from 2.5% at pH 6.5 to 3.3% at pH 7.0 and 7.5, before substantially decreasing to 1.6% at pH 8.0. The cause for low net N2O production rates at alkaline pH was assigned to high N2O reduction rates by the enzyme nitrous oxide reductase, which became relevant at pH > 7.5. Based on the results obtained in the Ph.D. study, operation of Partial Nitritation-Anammox at relatively long aerated phases, low specific ammonia removal rates and pH 8.0 is suggested to reduce N2O emissions from the process.

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