BENCHMARKING OF CONTROL STRATEGIES FOR THE PREVENTION OF NITROUS OXIDE ACCUMULATION IN WASTEWATER TREATMENT PLANTS

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Nitrous oxide (N_2O) is an ozone-depleting substance and a harmful greenhouse gas with a global warming potential three hundred times larger than that of carbon dioxide. Measurement campaigns at domestic wastewater treatment plants (WWTPs) have found significant N_2O emissions [1–5]. Specifically, N_2O is found to be produced during the typical WWT processes involved in the nitrogen removal [6]. Suboptimal operating conditions can trigger the biological processes producing this gas. For the purpose of reducing the carbon footprint of WWTPs, control strategies accomplishing those environmental conditions minimizing the production of N_2O have to be developed. Several investigations have been performed to find out how to reduce N_2O emissions [7,8]. There is a considerable amount of evidence showing that denitrification by ammonia-oxidizing bacteria (AOB) is the main producer of the total N_2O emitted [9]. For this reason, a control strategy regulating the aeration regime of the aerated tanks in the mainstream of WWTPs was developed by Boiocchi *et al.* [10]. The control strategy showed its effectiveness in drastically reducing the N_2O emissions. However, denitrification by heterotrophic bacteria (HB) can contribute to the total N_2O emitted as well. For this reason, control strategies minimizing N_2O produced during HB denitrification should be developed. N_2O is produced by HB as an intermediate compound during the reduction of nitrogen oxides, such as nitrate (NO_3^-) and/or nitrite (NO_2^-), to dinitrogen (N_2). If the rate of N_2O production is higher than the rate of N_2O reduction to N_2, N_2O accumulates in the liquid phase. Several factors are known to trigger the accumulation of N_2O during HB denitrification: high oxygen concentrations, low organic biodegradable carbon availability, low anoxic hydraulic retention time, and accumulation of nitrite and/or nitric oxide are the main factors. In full-scale WWTPs, N_2O production by heterotrophs can occur in the aerobic zone as a consequence of scarce oxygenation regime where nitrite accumulates. This contribution is already drastically reduced through the same controller used to minimize the N_2O production by AOB [10]. However, in pre-denitrification systems, the amount of N_2O accumulated in the anoxic zone ends up in the subsequent aerobic zone where it can be removed by stripping. Therefore, it is of interest to reduce the amount of N_2O accumulated in the anoxic zone due to incomplete HB denitrification. For this purpose, organic carbon addition in the anoxic zone of a pre-denitrification WWT plant has been chosen as a strategy for the minimization of N_2O by HB denitrification. However, excessive carbon addition to the anoxic zone can increase the consumption of oxygen by HB in the aerobic zone, thus decreasing the amount of oxygen available for autotrophic bacteria. This in turn can lead to a higher production of N_2O by AOB, or higher aeration costs if DO is controlled. A carbon addition trade-off is therefore necessary. Different configurations of Proportional Integral (PI) and fuzzy-logic controllers (FLCs) to reduce the anoxic N_2O accumulation are developed and compared. The capability of a PI control strategy, controlling the nitrate concentration in the effluent of the anoxic zone at 1 mg $N.L^{-1}$, in reducing N_2O accumulation is evaluated first. It is in fact expected that setting the nitrate concentration at low values would guarantee a more complete HB denitrification and thus reduce the amount of N_2O accumulated. However, the fixed set point may be suboptimal under some operating conditions. Using a lower set point for the nitrate concentration in the effluent from the anoxic zone could reduce the anoxic N_2O accumulation. This is especially the case in summer when the HB activity is higher due to the warmer temperatures. As an alternative to using a fixed set point, maximizing the NO_3^- removal efficiency in the anoxic zone is considered instead. It is expected that such a control strategy would decrease the N_2O accumulation in the anoxic zone independently from seasonal variations. Both Proportional Integral and fuzzy-logic control approaches will be adopted and compared in the simulation environment provided by the Benchmark Simulation Model n^{o}2 (BSM2) by Jeppsson *et al.* [12]. This simulation model provides an ideal configuration of typical full-scale pre-denitrification WWTPs where control strategies can be tested and compared in an unbiased way. The control strategies will be implemented in an extended version of the BSM2 with processes for the production of N_2O by both AOB and HB. Simulation results will be used to benchmark the performance of the different control

strategies using not only the N_2O effluent concentration from the anoxic zone, but also the N_2O emission factors, the effluent quality, and the operating costs.
The results will be of relevance for those plants aiming to reduce their N_2O emissions. Furthermore, the comparison between Proportional Integral and fuzzy-logic controllers will shed light on what the best approach is to be adopted for future control applications in WWTPs.

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