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Greenhouse gas emissions from and storm impacts on wastewater treatment plants: Process modelling and control

Thèse

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Abstract

This PhD thesis studied the interaction between wastewater treatment plants (WWTPs) and climate change, i.e. the production and emission of greenhouse gases (GHGs), especially nitrous oxide (N_2O), from WWTPs and the effect of the climate change induced more intense rain events on WWTPs. Both field measurements and full-scale modelling were pursued in this research.

A one-month measurement campaign was performed by installing on-line sensors at the aeration zone of the bioreactor of a 750,000 person equivalents WWTP, i.e. the Eindhoven WWTP in the Netherlands. The models of a full-scale virtual plant, i.e. the Benchmark Simulation Model No.2 (BSM2), and a full-scale real plant, i.e. the Eindhoven WWTP in the Netherlands, were extended with respect to GHG emissions, especially the pathways involving N_2O. Two types of extended Activated Sludge Models (ASM) were developed, i.e. ASMG1 for COD/N removal and ASMG2d for COD/N/P removal. Besides heterotrophic N_2O production, both proposed models include N_2O production by nitrite denitrification by ammonia-oxidizing bacteria (AOB) and describe the DO effect on AOB N_2O production by a modified Haldane kinetics term.

Results showed that AOB are the major producer of N_2O while the heterotrophs consume N_2O considerably. The high N_2O emissions occurred under high NH_4^+ and intermediate DO concentrations (up to 2.5 mg O_2/l in this work). Such conditions can be created by NH_4^+-DO cascade control which aims at reducing energy consumption by lowering the DO concentrations when the NH_4^+ concentration is sufficiently low. Moreover, this cascade controller is a low-gain feedback control strategy, i.e. a significant delay will occur between the detection of a NH_4^+ increase and the increase in aeration. All these properties lead to conditions favourable to N_2O production by AOB.

Different alternative scenarios and control strategies were compared in terms of effluent quality, operational cost and GHG emissions. In the framework of BSM2, a good balance among effluent quality, operational cost and GHG emissions was realized by implementing a pure DO feedback controller in the first aeration zone and a NH_4^+-DO cascade controller in the following two aeration zones and using either step feed or sludge recycling control to deal with hydraulic shocks.

Keywords:

Activated sludge, wastewater treatment, process control, field measurements, full-scale mathematical modelling, greenhouse gases, nitrous oxide, wet weather conditions