Modelling and simulation of a nitrification biofilter for drinking water purification

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Abstract

For the purification of pure and microbiologically safe drinking water, different treatment steps are necessary. One of those steps is the removal of ammonium, which can, e.g. be accomplished through nitrification in a biofilter. In this study, a model for such a nitrifying biofilter was developed and the model was consequentially used for scenario analysis. A protocol developed for characterisation of wastewater was used to characterise the biofilter influent. A comparison between measured and simulated effluent ammonium, nitrate and oxygen concentrations revealed that the predicting qualities of the constructed model are excellent. As such, the model could be used for further scenario analysis based on model simulations.

By simulating the behaviour of the biofilter, it was shown that its capacity to treat unexpected ammonium peaks in the summer time is very limited. Further simulations with the model showed that extensive aeration is not essential for nitrification as sufficiently dissolved oxygen is present in the influent. Therefore the aeration can be reduced to such a level that mixing is ensured. A final set of simulations showed that prolonged ammonium loads can be dealt with by reducing the influent flow rate. The amount of reduction depends of the operating temperature and influent ammonium concentration. The presented simulations can be used by the operators to reduce operating costs and as a decision tool in the case of high ammonium influent concentrations.

Keywords: drinking water purification, model-based optimisation, biofilter, ammonium removal, nitrification

Nomenclature

ASM	activated sludge model
BOD	biological oxygen demand (mgBOD/ℓ)
C^{sat}_{O2}	oxygen saturation concentration (mgO_2/ℓ)
COD	chemical oxygen demand (mgCOD/ℓ)
DO	dissolved oxygen (mgO_2/ℓ)
E(t')	dimensionless hydraulic residence time
HRT	hydraulic residence time (d)
K_La	oxygen transfer coefficient
NH_4^+	ammonium (mgN/ℓ)
S_S	biodegradable and soluble COD (mgCOD/ℓ)
S_I	non-biodegradable and soluble COD (mgCOD/ℓ)
T	temperature (°C)
T_{ref}	reference temperature (°C)
TIC	Theil's inequality coefficient
X_S	biodegradable and particulate COD (mgCOD/ℓ)
X_I	non-biodegradable and particulate COD (mgCOD/ℓ)
t	time (d)
t'	dimensionless time
y_i	simulated data points
$y_{i,m}$	measured data points
ρ	process rate (mgCOD/ℓ·d)
θ	Arrhenius constant
ϕ	temperature correction factor for oxygen transfer coefficient

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Introduction

The purification of pure and microbiologically safe drinking water is essential for limiting public health hazards. In Flanders, the northern part of Belgium, more and more surface water instead of groundwater is being used for drinking water purification in order to preserve the groundwater level. Surface water that is pumped into the drinking water purification site is treated with a series of biological and chemical techniques to ensure that the standards of safe drinking water are met. Examples of such techniques are the removal of ammonium through (biological) nitrification, the removal of phosphates and suspended particles by a combination of flocculation and filtration, the removal of micro-pollutants by active carbon filtration and disinfection with potassium hypochlorite.

Nowadays the operation of drinking water purification sites is based on experience (Rietveld, 2005). Water quality is monitored to prove that guidelines are met and, sometimes, laboratory tests are performed to determine, e.g. the dosage of chemicals. All these data, however, are scarcely used to improve day-to-day operation. The use of dynamic mathematical models, in combination with on-line monitoring and real-time control, can help to improve this day-to-day operation. This will lead to a better and more stable water quality, a better use of installed infrastructure and lower purification costs (Rietveld, 2005). Although dynamic modelling has been used frequently in other areas of chemical and environmental engineering, it has, however, only recently been applied in drinking water process modelling (Rietveld, 2005; Van der Helm and Rietveld, 2002; Rittman and Stillwell, 2002). In wastewater treatment modelling, for example, numerous examples exist of modelling, simulation and optimisation studies of both laboratory-scale and full-scale systems (Dochain and Vanrolleghem, 2001; Franks, 1972). The need for further research and the development of case studies is therefore evident.