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Implementing a respirometry-based model into BioWin software to simulate wastewater treatment plant operations

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ABSTRACT

The management of wastewater treatment plants to comply with new strict effluent criteria is a great concern: the activated sludge modeling, when supported by an accurate calibration process, could be an essential tool for this purpose. In the present paper, three WWTPs were characterized in order to support their up-grade. Influent characteristics and activated sludge performances were studied by application of respirometry. Plant operations were simulated by BioWin software (EnviroSim Associates Ltd., Canada). The goodness of the simulation, checked by the calculation of the average relative deviation between measured and simulated data, demonstrated that the model was able to predict the plant performances.

1. Introduction

In a recent paper, Insel et al. [1] rhetorically asked if the standard WWTP design methods are suitable for any municipal wastewater. Before the 1980, the answer to this question would probably have been positive: at that time, the goals required for wastewater treatment plant were the removal of solids and organic matter, so the plant design methods complied with these purposes. As is known, in the last two decades, the standards for wastewater constituent removal have changed: the new regulations request strict effluent criteria from wastewater treatment plants into the water bodies. Therefore, appropriate process design and control issues are of great importance to maintain sustainable and cost-effective treatment under variable environmental conditions [1].

Dynamic models of activated sludge processes have demonstrated to be an indispensable tool in plant design and management [1–4]; however, their calibration appears to be the bottleneck in their widespread application [5]. According to Petersen et al. [6], the calibration is the adaptation of the model to fit a certain set of information obtained from the full-scale WWTP under study. The calibration methodology of activated sludge plant models may be different depending on the targets of modeling [7].

Sin et al. [8] compared four calibration protocols for activated sludge models: the BIOMATH calibration protocol [9], the STOWA calibration protocol [10], the HSG guidelines [11] and the WERF protocol for model calibration [12]. As a result of the Sin et al. analysis, appeared that all the protocols have three major common point: the crucial influence of goal determinations in the calibration procedure, the significance of data collection, verification and reconciliation and the recommendation of validating the model with a data set obtained under different operating conditions than those of the calibration period. However, the four cited protocols diverged for three major aspects [8]: the planning of the measurement campaign, the experimental methods for influent characterization and the calibration method (selection of parameter subset, how to calibrate).

One of the major problems in activated sludge models (ASMs) application and calibration is to select a set of relevant parameters, which are necessary to achieve good prediction of the used model [7].

Mannina et al. [13] paid attention to the parameter subset selection. Their proposed calibration protocol consisted in two major phases performing several steps. In the first phase, a preliminary sensitivity analysis is carried out, selecting different subset of parameters, in order to reduce the number of model parameters to be calibrated. In the second phase, the model calibration is performed by means of a group-wise Monte Carlo technique.

Several authors reported the lists of more sensitive parameters in ASM calibration [7,14] including: the yield coefficient for heterotrophic biomass Y_H, the yield coefficient for autotrophic biomass Y_A, the maximum heterotrophic growth rate μ_{maxH}, the heterotrophic decay rate b_H, the maximum autotrophic growth

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rate μ_{maxA}, the half-saturation constant for organic substrate K_S, the half-saturation constant for ammonia K_{NH4}, the half-saturation constant for dissolved oxygen (related to autotrophs) K_{OA} and the anoxic ratio η_H.

These parameters are usually evaluated by means of respirometric tests [4,6,15–18]. Indeed, respiration rate is directly linked to two important biochemical processes that must be controlled in a WWTP: biomass growth and substrate consumption [19].

The present paper is the result of the field research carried out in three wastewater treatment plants, located in the Friuli Venezia Giulia (FVG) region, operating different technologies and serving a wide range of population equivalent. The study had the aim to support the up-grade design of the plants because, at that time, they showed some critical situations related to the nitrogen removal and/or to the variability on the influent pollutant load.

The WWTPs performances were studied by means of respirometric tests. The experimental results were used to calibrate a home-made activated sludge model that was further implemented in BioWin software (EnviroSim Associates Ltd., Canada).

2. Materials and methods

According to a study published by the Italian Statistic Institute [20], at the end of 2008, 693 WWTPs were in operation in the FVG region, with a served population of 1,772,906 person equivalent (P.E.). Secondary treatment was in place for 36% of these plants; while the 56% of the plants operated the primary treatment and only the 8% of the plants had the tertiary treatment.

This study focuses on three WWTPs, having secondary treatment and the characteristics (at the time of field study) reported below.

Plant #1 served a population of 7000 P.E., operating a time-based alternate cycles process. Anoxic and aerobic processes took place in the same basin that had a volume of 525 m^3. After passing a coarse bar screen (15 mm), the influent flowrate was channeled to biological reactor where the alternance of aerobic and anoxic conditions was controlled by time. The duration of aerobic phase was set equal to 4 h, while that of anoxic step was equal to 45 min.

Plant #2, serving 18,200 P.E., operated the activated sludge process with preanoxic MLE (Modified Ludzack–Ettinger) denitrification. Influent raw sewage was subjected to pass the pre-treatment units consisting of a grit screw and a horizontal-flow grit chamber. Primary sedimentation was no carried out in order to support the BNR process. In the biological unit, the flowrate of aerated sludge recirculated from aerobic reactor to anoxic section had the same value that those of influent.

Plant #3 was characterized by a seasonal variation of the influent wastewater with a maximum served population of 120,000 P.E. during the summertime. The water treatment line was divided in two independent sections: the physical–chemical treatment (with addition of aluminum chloride) and the biological activated sludge process. After preliminary treatment (grit screw, horizontal-flow grit chamber and preliminary settling), the influent flowrate was halved and the two resulting flowrates were piped to the respective section (the present study takes in account only the biological treatment line).

The characteristics of the examined plants and of the influent wastewaters are reported in Table 1.

2.1. Steps of the work

The work steps are depicted in Fig. 1. As stated before, the purpose of the study was the investigation of pollutants removal kinetics. To obtain it, an activated sludge model was developed and calibrated following several steps:

1. Information was collected regarding to plants layout and operations, long-time influent characterization and operational parameters. Collected data were checked calculating mass balances. Dedicated measuring campaigns were planned and carried out.
2. The characterization of the biological section of the plants was accomplished by application of the respirometric test, consisting in OUR, AUR and NUR.
3. The structure of biological model was formulated.
4. The model was calibrated using the results coming from respirometric assays. The calibration methodology was partially automated, meaning that some parameters were evaluated using a home-made software (hereinafter described). Steps from 1 to 4 were carried out for all the three examined WWTPs.
5. Step 5 (and also 6) regarded only the plant #2. It was preparatory to the operations simulation and consisted in the definition of aeration devices, controllers, flows and other operational parameters.
6. The model was implemented into BioWin software and validated using a data set of 11 months.

Table 1
WWTPs and influent flowrates characteristics.

Parameters	Units	Values		
		Plant #1	Plant #2	Plant #3
Influent WWs characteristics				
Total suspended solids	[mg TSS L^{-1}]	110 (64–148)	48 (17–108)	166 (65–282)
Chemical oxygen demand	[mg COD L^{-1}]	314 (197–417)	240 (53–373)	357 (163–622)
Ammonium nitrogen	[mg N L^{-1}]	35 (8–57)	20 (7–48)	32 (22–38)
Nitrate nitrogen	[mg N L^{-1}]	0.5 (0.0–1.3)	3.9 (2.0–8.0)	0.4 (0.0–1.1)
Flow rates				
Influent flow rate (average), Q_{IN}	[m^3 day^{-1}]	1400	3642	14,688
Recirculation of activated sludge (ratio), RAS	–	1	1	2
Recirculation of aerated sludge (ratio), R	–	n.a.	1	n.a.
Volumes/size				
Anoxic reactor	[m^3]	525 (Alternating)	208	n.a.
Aerobic reactor	[m^3]		514 × 2	2350
Final settling tank diameter	[m]	11.0	14.4	35.0
Side water depth of clarifier	[m]	2.5	2.5	3.0
Biological section operation				
MLVSS	[mg VSS L^{-1}]	2115	2883	4434
Solids retention time, SRT	[day]		8	
Hydraulic retention time, HRT	[h]	13	11.8	6.5
Total blower capacity, Q_{AIR}	[N m^3 h^{-1}]	400	732	