Full-scale application of the IAWQ ASM No. 2d model

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Abstract In the framework of the EU-funded TTP-UPM project (Technology Transfer Project – Urban Pollution Management) the waste water treatment plant (WWTP) of Tielt was modelled with the recently issued IAWQ ASM No. 2d model. Up to 41% of the total COD load is originating from a textile industry. A measurement campaign was conducted during a period with industrial discharge and a period with only domestic sewage. The stop of the industrial discharge resulted in a highly dynamic response of the system. Based on an expert-approach the calibration was obtained changing only four parameters (anaerobic hydrolysis reduction factor η_{fe}, reduction factor for denitrification η_{NO3}, the decay rate of autotrophs b_{AUT} and the decay rate of the bio-P organism building blocks b_{PAO}, b_{PHA}, b_{PP}). Influent fractionation remains a critical step within the model calibration. A proven procedure to characterise the influent determinants by standard physical chemical analysis failed to assess the influent COD fractions when the textile waste water is discharged to the WWTP. Selected bench-scale experiments, instead, succeeded in providing the adequate influent characterisation accuracy. For characterising the readily biodegradable COD fraction respirometry is to be preferred.

Keywords Activated Sludge Model No. 2d; biological phosphorus removal; modelling; dynamic simulation

Introduction

After publication of the Urban Pollution Management (UPM) procedure in the UK in 1994 (Anon. 1994; Dierickx *et al*., 1998), a European consortium has been set up to try out the application of this procedure in other European countries in the framework of the EC "Innovation Programme". This project is being coordinated by Aquafin and consists of a number of pilot studies. For the pilot study in Belgium the catchment area of Tielt was chosen. This paper focuses on the modelling part of the wastewater treatment plant (WWTP) of Tielt.

The WWTP of Tielt treats the wastewater for a catchment area of approximately 5,000 ha., a combination of urban areas, industrial estates and rural subcatchments. The plant discharges to a watercourse subject to the European guidelines on sensitive water bodies (EEC91/271). To meet the stringent local consents an extended aeration activated sludge plant has been operated since 1994 for nitrogen and phosphorus removal.

To model the complex processes involved in the biological reactors the recently issued IAWQ Activated Sludge Model (ASM) No. 2d (Henze *et al*., 1999) was selected. The ASM No. 2d provides a model structure capable of describing carbon oxidation, nitrification-denitrification and enhanced biological phosphorus removal (EBPR).

The quality of ASM No. 2d prediction depends on the quality of the wastewater characterisation and on the calibration of the many parameters involved in the model. However, many researchers (e.g. Gibson, 1992) have shown that for the application of dynamic process models or simulators, default input values for stoichiometry and most kinetic constants may be applied because they do not vary significantly from one waste-water to another. Therefore, during this research default values proposed by Henze *et al*. (1999) were only changed when strictly necessary. Efforts were thus focused on tuning of the most sensitive parameters within the model, being: the influent COD fractionation, the decay rate of autotrophic organisms (b_{aut}) and the bio-P activity parameters.

Materials and methods

Simulation tools and simulation models

All simulations were run with the WEST simulator package. To model the processes involved in the biological reactors the IAWQ ASM No. 2d (Henze *et al*., 1999) was selected. The clarifier model used is a 10-layered Takacs model (Takacs *et al*., 1991)

WWTP of Tielt: plant description

The WWTP of Tielt is of the Bio-Denipho type with a compartmentalised anaerobic tank of 1,000 m^3 and a two-ditch alternating system (5,938 m^3). Table 1 describes the characteristics of the different operational units. Table 2 summarises the main influent and effluent characteristics of the plant under study. The effluent consents for total nitrogen (TN) and total phosphorus (TP) are related to yearly averages, while the effluent consents for COD, BOD and SS are formulated in terms of 95% percentiles.

Table 3 gives an overview of the operational determinants of the WWTP of Tielt. The sludge loading rate in 1998 was on average 0.06 kg BOD/ kg TSS.d^{-1}.

Furthermore a significant industrial load reaches the plant. On average 41% of the total COD load is coming from a textile industry. This industrial discharge is relatively constant since the discharge passes first through an equalisation tank with a retention time of about 24 h.

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Table 1 Main characteristics of the operational units

Operational unit	Number	Dimensioning
Influent screw pump	4+1	482 m^3/h per screw pump
Step screens	2	6mm grid width
Sand trap (Dorr type)	2	–
Anaerobic tank	1	1,000 m^3
Aeration basins (Bio-denipho configuration)	2	Total Volume=5938 m^3
Secondary Clarifier (circular)	2	V= 2152 m^3/ Diameter=28 m
Stormtank	1	V= 2152 m^3/ Diameter=28 m

Table 2 Influent loading and effluent quality (1998) WWTP of Tielt

	Loading (kg/day)			Design capacity	Effluent mg/l			Consent
	Min.	Avg.	Max.	(kg/day)	Min.	Avg.	Max.	(mg/l)
BOD_5 (*)	136	1703	4316	1620	5	8	25	25
COD	533	6067	15148	4050	32	74	152	125
Tot-N	66	346	753	300	2.5	9.3	24.4	15
NH_4-N					0.1	2.3	20.2	
NO_3-N					0.2	3.5	13.6	
Tot-P	11	52	114	60	0.2	0.8	4.4	2
SS	217	2133	8645	2700	6	14	36	35

(*)BOD_5 performed with the addition of ATU

Table 3 Operational determinants of the WWTP of Tielt (1998)

Parameters	Min	Avg	Max.	Unit
Flow treated by biology	1655	12925	25073	m^3d^{-1}
Excess sludge flow	0	264	600	m^3d^{-1}
Return flow	2928	3480	3720	m^3d^{-1}
Anaerobic retention time	0.95	1.85	14.5	h
Sludge concentration in aeration	3.4	4.4	6.0	$gTSS.l^{-1}$

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Full–scale measurement campaign

Three automatic samplers (AS900, Sigma) were located respectively at the entrance of the biological unit, at the end of the anaerobic compartment and at the effluent. 24h composite samples were taken during a period of 30 days. Within that period, 2 h composite samples were collected for 48 hours. VFA determination was done only for those 2 h samples. All samples were cooled at 4°C and transported to the laboratory every day for analysis.

Influent samples were analysed for COD, COD_f, BOD_5, BOD_{21}, SS, VSS, KjN, NH_4-N, NO_3-N, NO_2-N, TP and PO_4-P. Samples of the effluent of the anaerobic tank were analysed for COD, COD_f, SS, VSS, KjN, KjN_f, NH_4-N, NO_3-N, NO_2-N and TP. The effluent samples were analysed for COD, COD_f, BOD_5, SS, KjN, NH_4-N, NO_3-N, NO_2-N, TP and PO_4-P.

Within the biological reactors, on-line monitoring of phosphate (PHOSPHAX, Dr. Lange) was conducted at the effluent of the anaerobic compartment.

During the measuring campaign a prolonged stop of the industrial discharge (11 days) was observed. This resulted in a decrease of the incoming COD load of about 50% leading to a significant increase of nitrate and phosphorus effluent concentrations. Hence two periods could be distinguished. The period during which industrial discharge was active is referred to as period 1, the period without industrial discharge as period 2.

Bench-scale SBR experiments: influent characterisation

The readily biodegradable substrate fraction was assessed by using the procedure proposed by Spanjers *et al*. (1995). The OUR curves were obtained with a side stream respirometer (RODTOX, Kelma), having a content of 10 litres of activated sludge. Dissolved oxygen was measured at ten seconds intervals. Temperature was kept constant at 22±0.5°C and pH was controlled between 7.2 and 7.5, which is within the same range as observed in the treatment plant. The response of activated sludge was determined for two raw influent samples with different strength (COD=1205 mg O_2/l and COD=788 mg O_2/l, respectively), the F/M ranging from 1/20 to 1/25. Nitrification was suppressed with 15 mg allylthiourea per litre of activated sludge. After the endogenous respiration rate was measured, a sample was added and the response was recorded. When the endogenous respiration was reached again and observed to be constant, a new identical sample was added. In this way, several curves out of the same experiment were obtained.

The inert particulate COD fraction X_I and the inert soluble COD fraction S_I were assessed by using the comparison method developed by Orhon *et al*. (1992), monitoring three 1-litre aerated batch reactors in parallel for a period long enough to reach a steady minimum soluble COD level.

In addition the physical-chemical characterisation as described by the Dutch guidelines and published by STOWA in 1996 (STOWA, 1996) was applied.

The k_{BOD} coefficient of the BOD degradation kinetics was estimated by recording the BOD curve using a sapromat device (Voith Gmbh, West Germany).

Results and discussion

Influent fractionation and model calibration/validation

In Table 4 the average measurement data obtained for period 1 and period 2 are presented. In the third column the set of equations needed for the influent characterisation according to the STOWA guidelines is presented.

Table 5 shows the results of the COD fractionation of the sewage according to the different procedures for the first period when the industrial discharge was still active:
- procedure 1: respirometry and off-line batch experiments
- procedure 2: physical-chemical characterisation according to the STOWA procedure with BOD_∞ set equal to BOD_{21} and $f_{BOD}=0.2$

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Table 4 Average measurement data and conversion formulae proposed by STOWA

Period 1	Measurements Period 2	STOWA conversion equations for model values	
Inflow	8853	6078	$m^3.d^{-1}$
Influent measurement			
COD	897	367	$COD = S_A + S_F + S_I + X_I + X_S$ (gives X_I)
BOD_5	277	133	$BCOD = \frac{1}{1-f_{BOD}}*BOD_\infty = S_A + S_F + X_S$ (gives X_S)
COD_f	479	82	$COD_f = S_A + S_F + S_I$ (gives S_F)
VFA	36	–	S_A (gives S_A)
K_j-N	34	39.4	$S_{NH4} = K_j\text{-}N - (i_{NSI}*S_I + i_{NSF}*S_F + i_{NXI}*X_I + i_{NXS}*X_S + i_{NXBIO}*X_{BIO})$
TP	5.9	8.3	$S_{PO4} = TP - (i_{PSI}*S_I + i_{PSF}*S_F + i_{PXI}*X_I + i_{PXS}*X_S + i_{PXBIO}*X_{BIO})$
Effluent measurements			
COD_f	56	44	$S_I = 0.90*COD_f$ (gives S_I)

All values in $mg.l^{-1}$, avg over 24 measuring points of 2 h composite samples
Note: f_{BOD}=0.2 (STOWA 1996)

Table 5 COD fractionation according to physical-chemical and off-line approaches during industrial discharge

COD Component	procedure 1	procedure 2	procedure 3
Inert particulate, X_I	19	10	35
Slowly biod., X_S	55	39	14
Readily biod., S_F+S_A	19	44	44
Ferment products, S_A	4	4	4
Inert, S_I	7	7	7

All values in % total COD

- procedure 3: physical-chemical characterisation according to the STOWA procedure with BOD_∞ derived from BOD_5 assuming a k_{BOD}=0.23 day^{-1} and f_{BOD}=0.2

The physical-chemical characterisation was applied on the 24 h composite samples. An average fractionation was obtained by making the average of the day to day fractionations. Applying this physical-chemical method resulted frequently in negative values for X_I in the case of procedure 2 and negative values for X_S in the case of procedure 3. The difference obtained between the two physical-chemical methods is striking. Using the BOD_{21} as a measure of BOD_∞ or calculating BOD_∞ starting from BOD_5 using the default k_{BOD} =0.23 day^{-1} as proposed by STOWA gives rise to completely different fractions for X_I and X_S. Two possible reasons can be put forward: either the BOD_{21} measurement could be considered as inaccurate or the proposed k_{BOD} of 0.23 day^{-1} could be doubted for the type of wastewater under consideration. To check the last hypothesis a sapromat test was run to estimate the k_{BOD} value for the wastewater of Tielt. Two repetitions were run resulting in respectively a k_{BOD} value of 0.39 and 0.40 day^{-1}. These k_{BOD} values give rise to even higher X_I fractions. Applying the different possible fractionations as obtained by this physical-chemical method did not allow a good calibration: the sludge balance did not fit.

On the contrary the off-line COD fractionation gave a good calibration of the sludge balance and the observed measurement data. The fitting towards the observed sludge production needed only minor adjustments (X_I = 17% COD instead of 19%), as can be seen in Figure 1.

When the influent contains a large proportion of textile effluent, little agreement is observed between the results of the bench-scale experiments and those of the STOWA procedure. Apparently the presence of a high level of filtered COD (51% of total COD) results in an erroneous influent fractionation using the physical-chemical approach. The hypothesis is that the 0.45 μm filtration step within the STOWA procedure led in this case to an
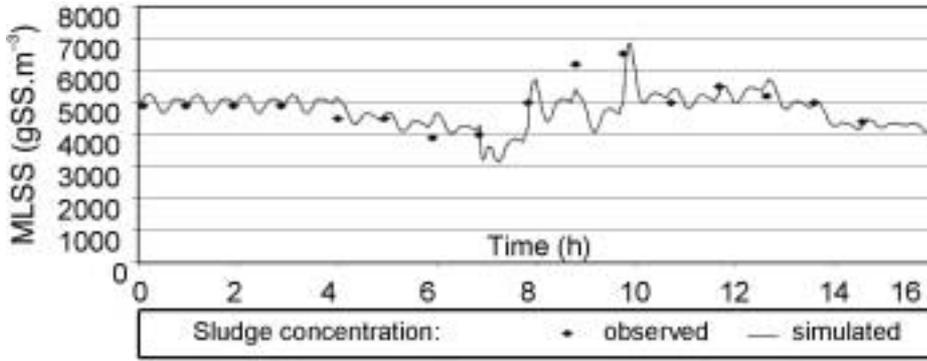
Figure 1 Simulated (lines) versus observed (points) MLSS concentrations, $X_I=17\%COD_{in}$

incorrect assessment of the readily biodegradable fraction $S_F + S_A$. Apparently due to the presence of this particular industrial waste stream a large part of the slowly biodegradable COD is very fine colloidal matter (range 0.1–0.45 μm) and passes through the 0.45μm filter. This becomes obvious when comparing the readily biodegradable COD ($S_a+S_f=S_s$) obtained by respirometry and the physical-chemical method.

The IAWQ ASM No. 2d model was calibrated on the first period. The calibration was carried out following the proposed iterative calibration loop: 1) sludge balance, 2) nitrification, 3) denitrification , 4) P-removal. The off-line influent characterisation was used as an initial good guess of the different influent COD fractions. The final influent fractions used for calibration were: $S_A=4\%$; $S_F=15\%$, $S_I=7\%$, $X_I=17\%$ and $X_S=57\%$. All other COD fractions in the influent were set to zero. Only 4 parameters were changed from the suggested default values (anaerobic hydrolysis reduction factor η_{fe}, reduction factor for denitrification η_{NO3}, the decay rate of autotrophs b_{AUT} and the decay rate of the PAO building blocks b_{PAO}, b_{PHA}, b_{PP}). Figure 2 and 3 show the calibration results for nitrogen and phosphorus.

During the temporary stop of the industrial discharge the influent was characterised with the STOWA procedure only. This time applying the physical-chemical method did not result in negative values, and the obtained readily biodegradable fraction was not unrealistically high. These facts in combination with a good fit of the sludge balance showed the physical-chemical method to be reliable in this case. The obtained influent fractionation is $X_I=20\%$; $X_S=57\%$; $S_F+S_A=12\%$; $S_I=11\%$ (all values in % total COD).
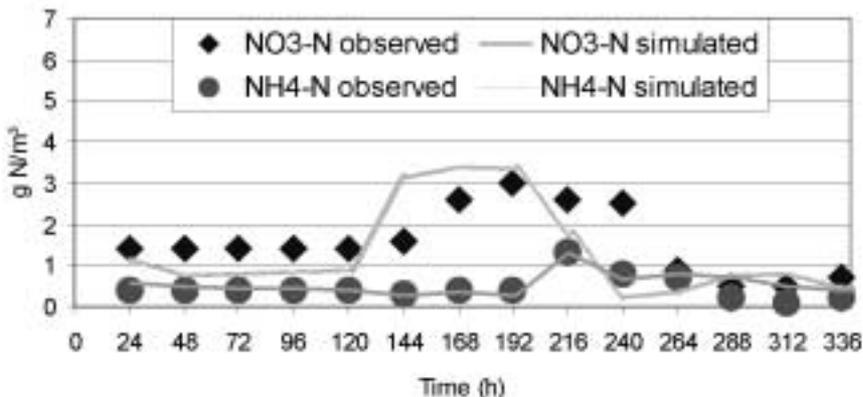

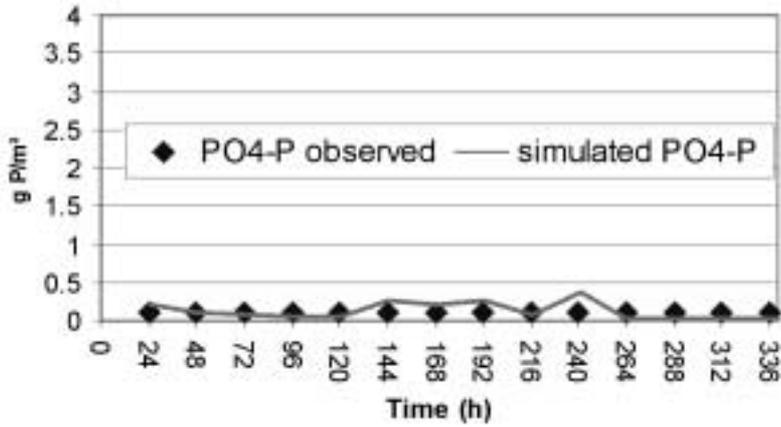**Figure 2** Effluent nitrogen simulated versus observed for period 1

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Figure 3 Effluent phosphorus simulated versus observed for period 1
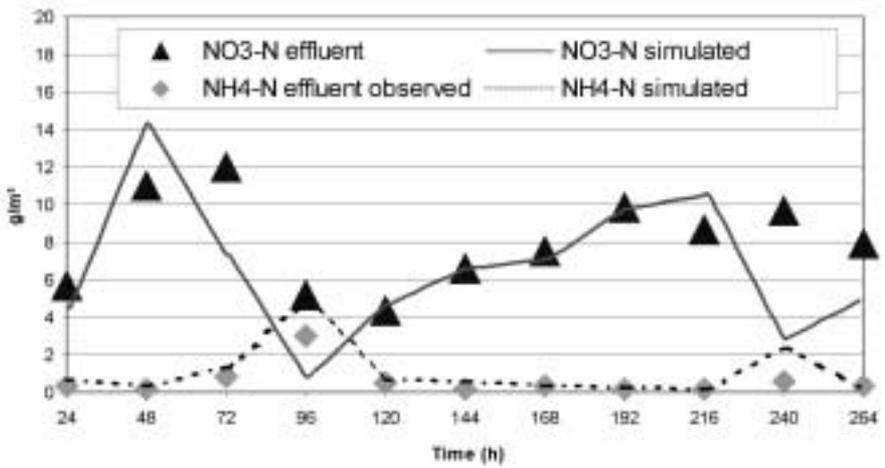

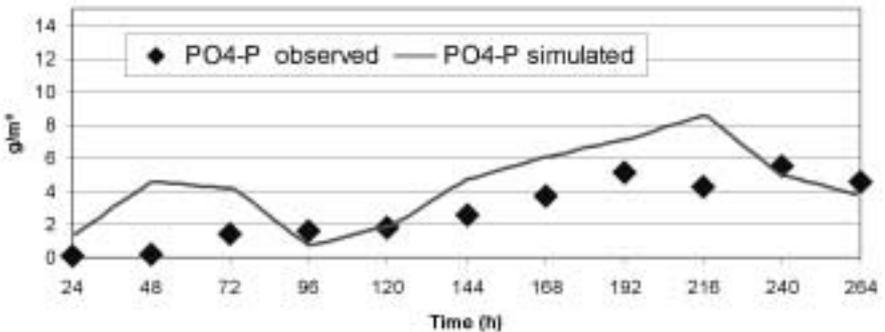**Figure 4** Effluent nitrogen simulated versus observed for period 2

Figure 5 Effluent phosphorus simulated versus observed for period 2

Figure 4 shows a relatively good validation for NH_4-N and NO_3-N. The relative over-estimation of NH_4-N and associated underestimation of NO_3-N at time instances 96 and 240 are most likely due to the sampling procedure. At these two periods storm weather was observed. Since 24 h composite samples were taken with a fixed sampling time interval, no flow proportional samples were obtained. This results in an overestimation of the

influent load fed to the simulator for the observed storm weather days. The validation of the P-removal reveals less satisfying results (Figure 5). Especially at the beginning of the period with a sharp decrease in COD influent concentrations, the model is overestimating the PO_4-P effluent concentration. Afterwards the trend is reproduced relatively well. A possible explanation of the initial overestimation of PO_4-P effluent in the transient period is related to biologically induced chemical P-precipitation (Maurer *et al.*, 1998; Maurer *et al.* 1999). Comparing the simulated PO_4-P effluent concentration of the anaerobic tank (30–35 g P/m^3) with the observed one (15–20 g/m^3) indicates a significant difference. This observation in combination with a relatively higher pH (7.3–7.5) strongly supports the hypothesis of biologically induced chemical P-precipitation. Further research is needed to confirm this hypothesis.

Finally this research clearly shows the positive impact of the industrial waste stream on overall nutrient removal. The textile waste stream provides the extra readily biodegradable substrate needed to ensure a very stable and outstanding effluent quality in terms of phosphorus and nitrogen.

Model application

The obtained model has been used for scenario-analysis within the framework of the TTP-UPM project. One of the scenarios evaluated by modelling is to double the hydraulic loading of the biological unit using the available storm tank as an extra clarifier. The model-based evaluation biological system was capable of treating a hydraulic loading up to $6Q_{14}$ (instead of the standard practice of treating $3Q_{14}$ biologically) while reducing the total pollutant discharge into the receiving waterbody (Carrette *et al.*, 2000). This operation mode will be implemented at full scale.

Conclusions

The predictive power of the IAWQ ASM No. 2d model was evaluated on a full-scale installation. Only four parameters were changed for calibrating the model. For the specific case under study the model proved to deliver acceptable predictions on NH_4-N and NO_3-N. The prediction of PO_4-P in the effluent turned out to be more conservative than the observed data. However this might be due to the interference with biologically mediated chemical P-precipitation.

Influent fractionation remains a critical step within the model calibration. A proven procedure to characterise the influent determinants by standard physical chemical analysis fails to assess the influent COD fractions when the textile wastewater is discharged to the STP. Due to the high sensitivity of the model prediction to the influent fractionation, this could lead to very misleading interpretations. Selected bench-scale experiments, instead, succeeded in providing the adequate influent characterisation accuracy. For characterising the readily biodegradable COD fraction, respirometry is to be preferred.

Furthermore this case study clearly demonstrates that there are some inherent advantages to treating textile waste water streams of this kind to maintain a stable EBPR system.

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