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Integrating ultrasonic disintegration in activated sludge wastewater treatment plant modeling

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ABSTRACT

This paper presents an integrated mathematical model that is capable of predicting and assessing the impact of ultrasonic (US) treatment on the excess activated sludge production in an activated sludge wastewater treatment system. Biological processes in the reactor are simulated in Matlab®/Simulink by the ASM1 model into which two algebraic equations, which capture the US treatment, are integrated. Calibration and validation data series come from a pilot plant installed at two locations, i.e. at a communal wastewater treatment plant (Mechelen-Noord) and at an industrial food flavor production site Haasrode, both located in the Flanders region of Belgium. The results show that the built-up model is capable of correctly predicting excess sludge reduction in the treatment system (which is a sequencing batch reactor in both cases). A reduction of approximately 42% for the communal case study can be reported, while the result obtained for the industrial case study, characterized by a very high organic loading, is quite comparable, i.e. about 38%. The latter represents a huge amount of excess sludge avoided given the nominally very high sludge production rate. The model can now be exploited to maximize the excess sludge reduction while minimizing the US operational costs.

Keywords: Wastewater treatment modeling; Ultrasonic disintegration; Excess activated sludge reduction

1. Introduction

Notwithstanding the major advantages of biological wastewater treatment systems, the inherent production of excess sludge remains a significant financial burden. Handling expense represents 30–40% of the capital cost and about 50% of the operating cost of many wastewater treatment facilities [1]. Thus, a number of methods, including mechanical or chemical treatment, have been used to reduce the excess

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amount of activated sludge. Among mechanical treatments, ultrasound is highly promising [2].

The main purpose of ultrasonic (US) treatment of sludge is to promote cell lysis due to which organic compounds are released. Over the last few years, much research has been carried out to prove the advantages of ultrasound for activated sludge disintegration. A summary of ultrasonic treatment of waste sludge can be found in the recent literature [3,4]. Most reported applications of ultrasonic cell disintegrating are, however, situated in the field of pretreatment for anaerobic digestion by applying ultrasound on *waste* activated sludge [5–9]. By disrupting the cell (floc) structures, this cellular organic matter is transformed in more easily accessible and more easily biodegradable matter for the anaerobic digestion.

One of the most recent ones is a study on high-frequency ultrasound, in which floc disintegration and surfactants removal were combined [10]. In this research, the authors proved that sludge ultrasound treatment leads to an overall improvement of digestion performances.

In the here presented research, we specifically aim at excess sludge reduction by applying ultrasound on *return* activated sludge. The organic matter that is released due to the ultrasound disintegration is consumed in a process called *cryptic growth*. Due to the fact that the yield coefficient of biomass on substrate is less than one (most often around 0.6), the overall biomass production is reduced. Only few studies focus on developing mathematical models for ultrasonic treatment [11–13]. The mentioned papers only focus on predicting an efficiency factor for the release of soluble COD (sCOD) and provide no information on the release of nutrients and the instantaneous reduction of volatile suspended solids (VSS). Moreover, often insufficient influential variables are included in the model equations, making the models only applicable on the training data-set of their own experimental research. The ultrasound model that is used in this research is developed and discussed by Lambert et al. [14]. It is a simple model but contains all influential input variables, that can predict not only the sCOD release but also the nutrients release (ortho-PO_4-P and soluble Kjeldahl nitrogen (KJN)) and VSS reduction, simultaneously. In addition, other research does not consider yet the ultrasonic treatment in combination with the conventional activated sludge process since their main interest is optimizing and improving the efficiency of the ultrasonic-activated sludge treatment prior to sludge anaerobic digestion. In this study, the selected US device model is integrated directly in the operation of a conventional sequencing batch reactor (SBR) system to model the whole process, in which focuses are given to the reuse of treated sludge as a carbon source and to the reduction of overall biomass excess production. Thus, being able to simulate how much organic matter will be released and how much excess sludge will be avoided in function of the ultrasound treatment settings offers great advantages in optimizing the economics of the process.

Therefore, the aim of this paper is to develop an integrated mathematical model which captures the impact of ultrasound treatment on excess activated sludge production and which can later on be exploited in optimizing the operational settings of the US treatment. After the introduction of the materials and models (Section 2), the model implementation, calibration, and validation are presented. For the calibration, a communal wastewater treatment plant is used, while the validation is performed on the basis of an industrial case study (Section 3). Finally, Section 4 summarizes the main conclusions of this work.

2. Materials and models

2.1. Materials

This study relies on data from a pilot plant depicted in Fig. 1, which has two parallel reactors of the SBR type (Bio1 and Bio2), each having a volume of 1 m^3. The pilot plant was installed at two locations in Flanders, Belgium. From October 2009 to December 2011, the pilot plant was operated at the communal wastewater treatment plant of Aquafin in Mechelen-Noord, which will be denoted by WWTP Mechelen-Noord. In 2013, the reactor and all its side-equipment was moved to a food flavor-producing factory in

Fig. 1. The SBR pilot plant of this study.

Haasrode, indicated as the WWTP Haasrode. While the former plant is characterized by a low organic loading and was tested as proof of principle, the other exhibits an extremely high organic loading which induces, under normal operation, significant amounts of excess sludge for which, hence, the ultrasound treatment could be highly beneficial.

2.1.1. WWTP Mechelen-Noord

For the case in Mechelen-Noord, 0.9 m^3 of wastewater is treated per day divided into three cycles, which each last, hence, for 8 h. As illustrated in Fig. 2, the settings are the following: the filling and aeration time is 5.5 h followed by 0.5 h final aeration. The settling phase lasts for 1 h, during the last 10 min of which 20 L of sludge is withdrawn, and led to the US equipment before being returned to the biodegradation tank during the first subsequent feeding phase. The decanting phase lasts for 1 h. While in general, the aeration of the SBR system is steered by a more complicated scheme, the process at Mechelen-Noord can, due to the low organic loading (expressed in chemical oxygen demand—COD), easily reach 1 mg/L during the nitrification period. Thus, along the reaction phase (5.5 h), the system alternately runs with a fixed period of 20 min for nitrification and 20 min for denitrification.

When the dissolved oxygen (DO) reaches 3 mg/L during the aeration phase, the aeration is switched off and is turned on again when DO drops below 1 mg/L. When the aeration time has expired, the anoxic phase starts.

During each 20 min of anoxic phase, influent is added to the reactor via a 200 L/h pump until the desired amount of wastewater is reached, i.e. 300 L/cycle.

One of the two reactors (Bio2) is connected to the US treatment to examine its impact on sludge reduction and on the overall treatment performance. The sludge age is initially maintained at 25 d for both reactors by wasting 1/25 volume of the tanks every day (36 L/d corresponding to 12 L/cycle).

2.1.2. WWTP Haasrode

Due to the different compositions of the influent in Haasrode, i.e. a high organically loaded influent, operational settings of the SBR are adjusted accordingly. Only 1 cycle/d is implemented to treat 60 L/d.

As illustrated in Fig. 3, the settings are the following: the filling and aeration time is 16.5 + 3 h, the first block is a sequence of aerated and anoxic (+filling) phases, while during the last 3 h, one continuously aerates. Then, the reactor turns into a settling phase (1.5 h) and decantation/rest phase (3 h).

During the aeration/anoxic + filling phase, 1-h long aeration phases are followed by 1-h long filling and denitrification phases. The procedure is repeated until the feeding/aeration time (16.5 h) is over. DO during the aeration is controlled between 1 and 2 mg/L.

In contrast to the case of WWTP Mechelen-Noord, we did not waste any sludge during the settling phase to study and keep track of the accumulation of biomass in both reactors. This sludge *excess* monitoring is believed to be an appropriate way to verify the positive impact of the ultrasound device on the excess sludge reduction.

2.1.3. Matlab®/Simulink implementation

Fig. 4 shows how the two SBR systems (in Mechelen-Noord and Haasrode) are implemented in Simulink. The overall SBR model is built-up using the default blocks. These blocks are connected to each other by a single line, which will transform (one way) signals containing information of flow, concentration, time, etc. to the input ports of the receiving blocks.

The three main blocks of an SBR cycle can be seen on the schematic diagram of the system in Fig. 4, i.e. a reaction + filling, a settling, and a decanting block. The biological processes are implemented in the reaction + filling block in which the alternating aerated

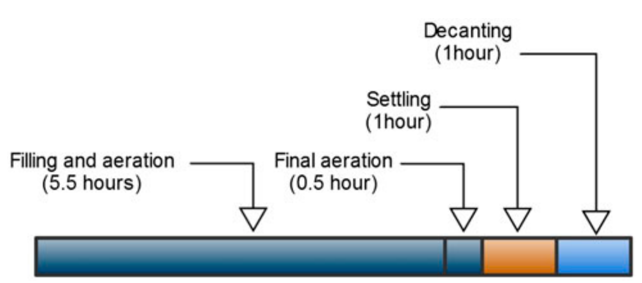

Fig. 2. Diagram of one cycle (8 h) of the SBR at WWTP Mechelen-Noord.

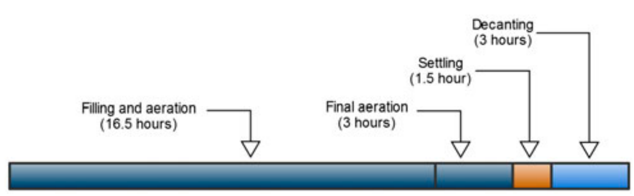

Fig. 3. Diagram of one cycle (24 h) of the SBR at WWTP Haasrode.

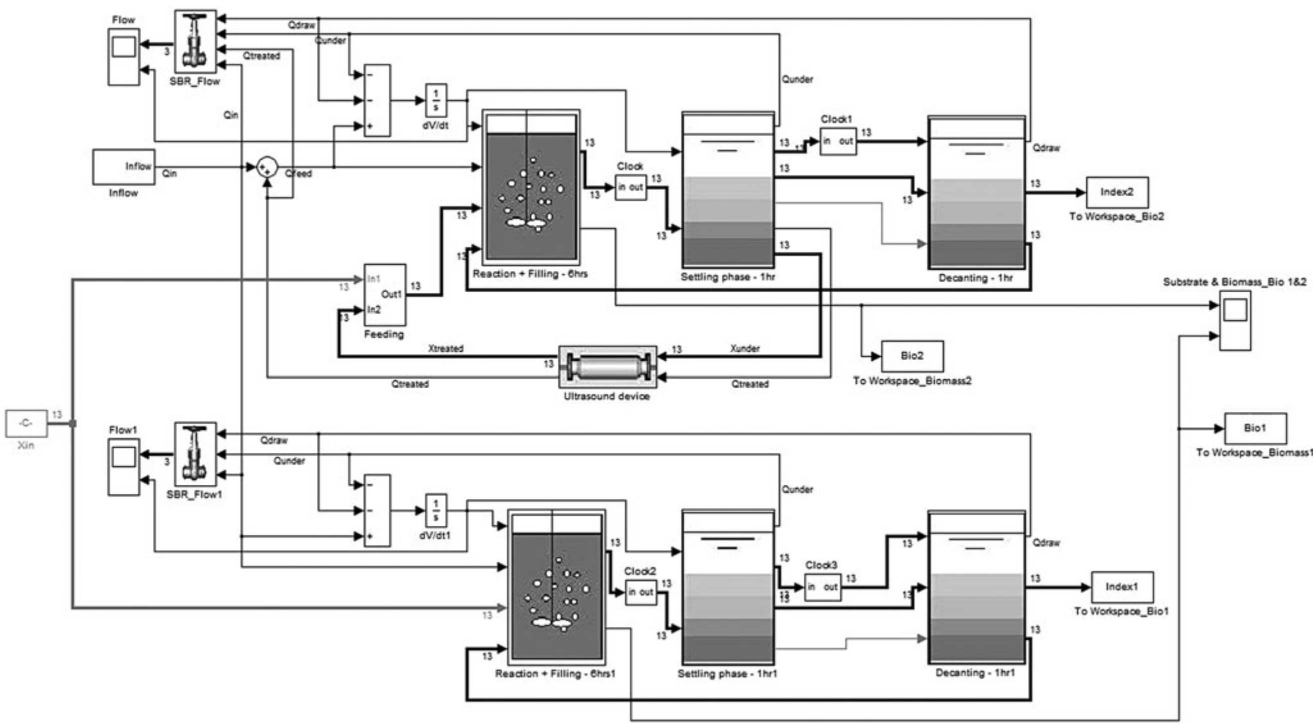

Fig. 4. Simulink implementation of SBR systems. Lower: control SBR Bio1 and upper: US treated SBR Bio2.

and non-aerated phases are imposed. The settling process is modeled and integrated in the block for settling. The decanting block regulates how the effluent is withdrawn from the reactor. Under each block, subsystems are employed to be able to use common parameters for the internal calculations. In addition, in the Bio2 SBR, an ultrasound block is integrated in which the algebraic equations for the ultrasonic treatment are implemented.

Apart from simple blocks which can be used directly from the library of Simulink, one also has to combine blocks to represent the typical working conditions of the SBR. For instance, due to the working principle of an SBR system, at the end of one cycle, the system has to be reset to start a new one. In this case, an integrator has to be used with an external reset signal (when the time of a cycle has expired) and the conditions at the end of the previous cycle have to be used for the initial conditions of the current one.

2.1.4. Ultrasonic device

The plug-flow-type ultrasonic device consists of a Bandelin reactor bloc SB® 5.1-1002 with an array of 20 transducers and an ultrasound generator (1001 T). In this pilot system, the activated sludge is recycled over the plug-flow reactor with a flow rate of 514 L/h. The system has a fixed frequency of 25 kHz, and a variable power output with a maximum of 1,000 W.

2.2. Models

2.2.1. Biodegradation

In order to simulate the biodegradation processes, the ASM1 model [15] has been employed. Default input fractionation is done to transform the incoming measurements regarding organic material and nitrogen components, to state variables of the ASM1 model. The available averaged influent data of the Mechelen-Noord case is summarized in Table 1, while

Table 1
Averaged influent data at Mechelen-Noord

Component	Concentration (mg/L)
COD	224
sCOD	183
TN	39
TP	5
Ortho-P	4
NH_4-N	29
NO_3-N	1
SS	158

records of measurements at Haasrode are shown in Table 2.

2.2.2. Settling

A point settler model is selected to simulate the sedimentation process, such that we assume that all particulate components settle well with only a small fraction of them escaping through the effluent. A point settler model is selected to simulate the sedimentation process, such that we assume that all particulate components settle well with only a small fraction of them escaping through the effluent. The selection of this simple settler model is due to the fact that for the given case studies, the sludge thickened well, i.e. the observed concentration of MLSS was doubled during the settling phase. Hence, using a more advanced settling model will complicate the whole process without yielding additional information. A simple settling model will, furthermore, facilitate the calibration and validation process such that focus could be given to the US model and the ASM1 model. In general, a thickening factor of 2 and a non-settleable fraction of suspended solids of 0.005 were thus used to calculate the concentration of the underflow and effluent biomass (MLSS) concentrations from the SBR.

2.2.3. Ultrasonic sludge disintegration

The working principles of the ultrasonic device are based on the research on sCOD release and instantaneous sludge reduction [14]. A partial least squares (PLS)-based model consisting of all influential input variables was developed to predict not only sCOD release but also the nutrients release and VSS reduction simultaneously. More specifically, on the basis of the known or user-defined input values of the specific energy E_s (kJ kg DS^{-1}), the ultrasonic power density D_s (W/mL), the US power intensity I_s (W/cm^2), the pH and the initial ML(V)SS concentration (g DS L^{-1}), the resulting concentrations of released sCOD, instantaneous ML(V)SS reduction, and other components such as soluble KJN, ammonium, ortho-PO_4-P are predicted.

A principal component analysis was carried out on the input and output data matrix of obtained experimental observations that will be used as training data. In this way, certain correlated input variables and independent output variables can be removed from the model, in order to increase its simplicity and predictive nature. Then, the model was built on the basis of PLS regression and a part of the observations was used to validate the predictive strength of the model. After checking this correlation, the regression coefficients of the PLS model with three components were determined as can be seen from Table 3. In this paper, we focus on sCOD release and MLSS reduction. Further information regarding the release of soluble KJN, ammonium, and ortho-PO_4-P and on the PLS modeling process itself can be obtained from [14]. With the aid of these regression coefficients, it is possible to construct the equations to describe the release of sCOD and to predict also the related reduction of activated sludge on the basis of the initial characteristics of the activated sludge ($MLSS_0$ and $MLVSS_0$) and the operational conditions of the US treatment (E_s, pH, I_s and D_s). The high quality of the model can be inferred from Fig. 5, where the correlation statistics between the measured and calculated valued for MLSS reduction and the sCOD release are illustrated.

Two algebraic equations of the PLS model can be obtained from Table 3, showing the relation between the sCOD release and the reduction MLSS with the initial $MLSS_0$, as well as with the operating conditions of the ultrasound device. These equations are integrated in the ultrasound model which will be discussed in the next sections.

$$\begin{aligned} MLSS/MLSS_0 = {} & 1.58e+00 - 3.62e-06 \times E_s \\ & -9.30e-03 \times MLSS_0 - 8.74e-03 \times MLVSS_0 \\ & -1.74e-04 \times I_s - 7.82e-05 \times D_s - 6.55e-02 \times pH \end{aligned} \quad (1)$$

$$\begin{aligned} sCOD/MLSS_0 = {} & 7.30e+02 + 5.25e-03 \times E_s \\ & +4.16e+00 \times MLSS_0 + 3.67e+00 \times MLVSS_0 \\ & +1.31e+00 \times I_s + 2.98e-02 \times D_s + 9.01e+01 \times pH \end{aligned} \quad (2)$$

Table 2
Two-week influent data at WWTP Haasrode

Component Time	COD mg/L	NO_3-N mg/L	Ortho-P mg/L	KJN mg/L
10-08-13	7,700	12	16.4	N/A
12-08-13	8,100	9	16.8	32.2
14-08-13	8,200	9	12.0	N/A
15-08-13	7,900	10	13.5	44.3
17-08-13	8,700	5	11.6	46.0
19-08-13	8,600	8	12.8	41.2
21-08-13	7,200	29	9.4	48.9
23-08-13	6,900	N/A	12.1	29.9
25-08-13	7,200	N/A	26.2	28.1
27-08-13	6,700	N/A	21.8	27.5
29-08-13	6,700	N/A	17.7	36.7
31-08-13	7,400	N/A	14.5	35.5
02-09-13	7,900	N/A	20.2	35.5

Table 3
Overview of the regression coefficients of the PLS model to calculate the release of sCOD and reduction in MLSS

Model output: dependent output variables→	$MLSS/MLSS_0$		$sCOD/MLSS_0$	
Model input: independent input variables↓	Regression coefficients	Unit of coefficient	Regression coefficients	Unit of coefficient
Intercept	1.58e + 00	(g DS/g DS)	−7.30e + 02	(mg O_2/g DS)
E_s	−3.62e − 06	$(kJ/kg\ DS)^{-1}$	5.25e − 03	$(kJ/kg\ DS)^{-1}$
$MLSS_0$	−9.30e − 03	$(g\ DS/L)^{-1}$	4.16e + 00	$(g\ DS/L)^{-1}$
$MLVSS_0$	−8.74e − 03	$(g\ VSS/L)^{-1}$	3.67e + 00	$(g\ VSS/L)^{-1}$
I_s	−1.74e − 04	$(W/cm^2)^{-1}$	1.31e + 00	$(W/cm^2)^{-1}$
D_s	−7.82e − 05	$(W/mL)^{-1}$	2.98e − 02	$(W/mL)^{-1}$
pH	−6.55e − 02	$(-\log[H^+])^{-1}$	9.01e + 01	$(-\log[H^+])^{-1}$

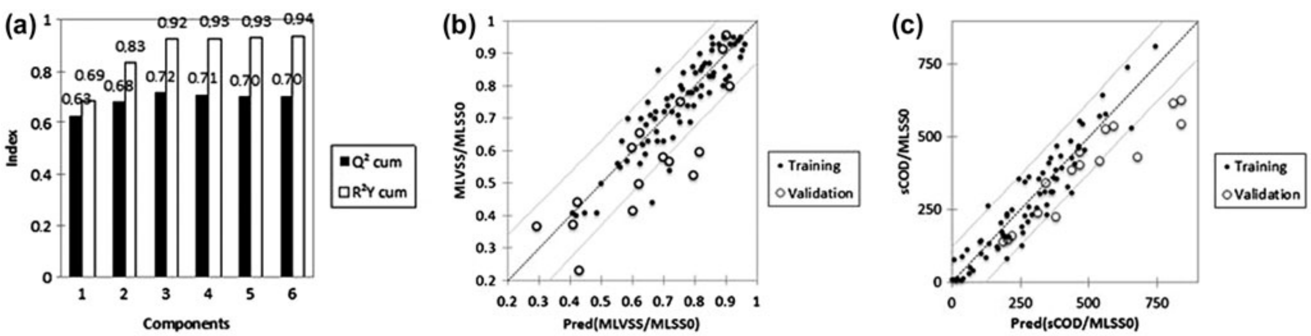

Fig. 5. (a) The evolution of R^2Ycum and Q^2cum with an increasing number of latent components of the PLS model and correlation statistics between the measured values and calculated values for (b) the MLSS reduction, (c) the sCOD release. More information can be found in [14].

As the concentration of biomass observed in ASM1 is active biomass (viable microbial biomass), and due to the limitation during the experimental period, a typical value of active biomass fraction in MLVSS of 50% was selected [16]. Under this assumption, the MLVSS will be equal to two times the sum of the heterotrophic X_{BH} and autotrophic X_{BA} biomass. Sampling and analysis results have shown that the ratio between MLVSS and MLSS was approximately 70%. This will be used to calculate the $MLSS_0$ in the above equations based on $MLVSS_0$. Furthermore, the sCOD values at the exit of the US device are assumed to be readily available organic matter, denoted by S_S in ASM1 terminology.

3. Results and discussion

3.1. WWTP Mechelen-Noord

3.1.1. Mass balance

Firstly, the liquid mass balance was checked by verifying the incoming and outgoing flows of the SBR system. As an illustration, the evolution of the flow and volume of Bio2 in Mechelen-Noord is depicted in Figs. 6 and 7, respectively. During the last 10 min of the 1 h of settling phase, 12 L is wasted from the reactor by an underflow of 1.73 m^3/d. In addition, the treated sludge flow from the sludge tank is taken into account, i.e. 20 L/cycle; due to which the under flow Q_{under} amounts to 4.61 m^3/d. In order to redistribute the sludge flow to the normal inflow, 20 L of treated sludge is added to the first subcycle.

That means 20 L is added during the first 20 min of denitrification with a magnitude of 1.44 m^3/d. Thus, the influent to the SBR will be the sum of the normal influent (4.80 m^3/d) and the sludge flow (1.44 m^3/d), i.e. 6.24 m^3/d for the first subcycle. Treated water is withdrawn during 1 h of decanting phase with a flow Q_{draw} of 6.91 m^3/d.

3.1.2. Calibration of the ASM1 model

As this study aims at validating the integrated model on real WWTP data, care has to be taken that a

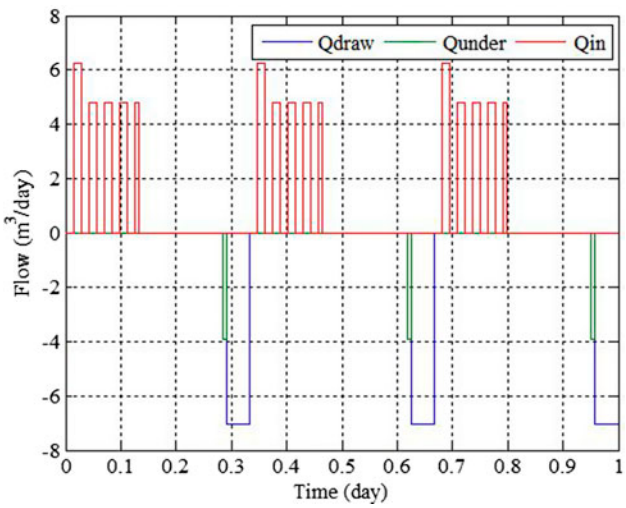

Fig. 6. Flow pattern during one cycle in SBR Bio2 at Mechelen-Noord.

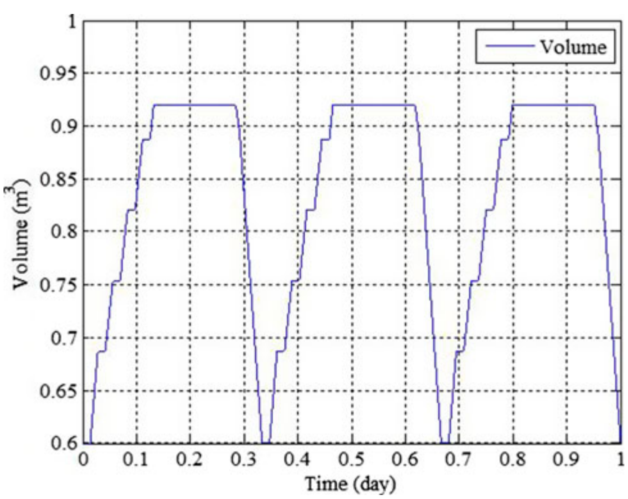

Fig. 7. Volume pattern during one cycle in SBR Bio2 at Mechelen-Noord.

proper fit exists between the control SBR values and the real data. Since this study did not allow for a very in-depth calibration of stoichiometric and kinetic parameters, the default parameters were implemented in a preliminary testing phase. Herewith, we were, however, unable to attain the experimentally measured steady-state biomass concentrations during the biodegradation phases. Based on the work done by Weijers and Vanrolleghem [17] and personal communication with activated sludge modeling experts, four parameters that have the largest influence on the active biomass concentration in the ASM1 model (and, hence, on the ML(V)SS concentration that is targeted by the sludge disintegration) were studied to select the most sensitive one, i.e. the maximum specific growth rate for heterotrophic biomass μ_H, the decay coefficient for heterotrophic biomass b_H, the correction factor for anoxic growth of heterotrophs η_g, and the yield for heterotrophic growth Y_H. Simulations were first carried out with the default values of the above parameters, which are summarized in Table 4.

The influence of the four mentioned parameters was studied and while for the parameters μ_H, b_H, η_g, and Y_H, the default values seemed reasonable, the decay coefficient value b_H was found to be high at 20˚C, i.e. 0.4. A line search optimization for this parameter has proved that a lower value is more suitable to express the evolution of biomass concentration in the reactor. Table 5 shows the biomass concentration in the SBR at steady state with different values of b_H.

It is evident that a higher biomass concentration is achieved when a low decay coefficient is employed. With a b_H value of 0.1, the active biomass concentration in the reactor is 0.91 g/L. Given that it is assumed that the active biomass concentration is 50% of the MLVSS, the latter will be 1.82 g/L, and the MLSS value is approximately 2.6 g/L. These values are found to be in line with the experimental data (2.8 g/L) in the not-treated Bio1 reactor. The matching level of the calibration step thus reaches nearly 93%. The selected value of the decay coefficient b_H was then also used for the US-coupled Bio2 reactor. With respect to the operational parameters of the ultrasound, the operational settings are presented in Table 6.

It is obvious that in order for Bio2 to have (approximately) the same biomass concentration as in Bio1, less sludge can be wasted. With an SRT of 25 d, the simulated active biomass concentration is 0.67 g/L for Bio2 and 0.91 g/L for Bio1.

To have an easy way of calculating the amount of excess sludge that can be avoided, it is simulated how much less one can waste per day if the target is to maintain the same biomass concentration as in the not-treated reactor Bio1. Table 7 shows the observed biomass concentration in comparison with the values of wasted sludge and the corresponding sludge age SRT.

It is clear from Table 7 that by wasting 7 L/cycle, the biomass concentration in Bio2 can be kept almost the same as in Bio1. A quick calculation shows that the amount of sludge that can be wasted less from Bio2 in comparison with Bio1 is 15 L/d, which represents a reduction of 42%. This prediction corresponds to the real values. This result also means that the SRT in Bio2 can be increased to 43 d instead of being 25 d, as in Bio1.

Table 4
Default values of the considered ASM1 parameters

ASM1 parameters	μ_H (d^{-1})	b_H (d^{-1})	η_g (–)	Y_H (gCOD/gCOD)
Default values	6.0	0.40	0.8	0.67

Table 5
Calibration of the decay rate parameter b_H

b_H (d^{-1})	0.4	0.3	0.2	0.1
Biomass (X_{BH}) (g/L)	0.42	0.63	0.75	0.91

Table 6
Operational parameters of the ultrasound device

Parameters	Optimal value
Specific energy E_s (kJ kg DS^{-1})	10,000
Ultrasonic density D_s (W/mL)	0.66
Ultrasonic intensity I_s (W/cm^2)	500
pH	7.5

Table 7
Active biomass in the reactor with different SRT

Wasted sludge (L/cycle)	12	10	8	7	6
SRT (d)	25	30	37.5	43	50
Active biomass (g/L)	0.67	0.75	0.85	0.91	0.98

3.2. WWTP Haasrode

In this case study, the impact of the ultrasound treatment on the overall performance of the activated sludge system was further studied, now by monitoring the yields of biomass in both reactors. This study was done by running both systems without wasting any sludge during the settling phase. The SBR system was kept running from 10 August 2013 until 2 September 2013, during which also non-feeding periods occurred due to technical problems. As mentioned previously, this system ran with only 1 cycle/d and only 60 L of effluent was withdrawn from both bioreactors during the idle phase. In Bio2, 25 L of thickened sludge was sent to the ultrasonic device for treatment before being led to the sludge storage tank and returned to the reactor with normal influent during anoxic phases. In general, all the sludge should be kept in the system under these operational conditions, and biomass is expected to be accumulated in both bioreactors but at a different rate. The latter allows the comparison and quantification of the excess sludge. As the MLSS concentration is measured in reality by means of sensors installed 5 cm from the bottom of the tank, the difference in MLSS concentration in both reactors can be used to judge the performance of the ultrasound treatment and by recalculating the biomass concentrations from the model (as explained before), the simulated values can be compared with the real values.

Fig. 10 shows the MLSS concentration in Bio1 and Bio2 after 23 d of simulations. These profiles were then collated with the corresponding experimental data to validate the prediction of the model. The agreement between simulated and experimental data can be appreciated from Figs. 8 and 9. One can see clearly the impact of non-feeding phases where no influent is added to both reactors, leading to the fact that there was no increase in MLSS and even a decrease due the starvation period. MLSS increases again when influent is added to the reactors.

To investigate the goodness of the validation in terms of MLSS concentration, three common quantitative indicators are calculated, i.e. the R^2 value, the root mean square error (RMSE) and the cross-validation RMSE. The values are summarized in Table 8.

From the R^2 values, the graphically observed goodness of fit can be validated, but given the limited available data, the cross-validation RMSE should be considered with care.

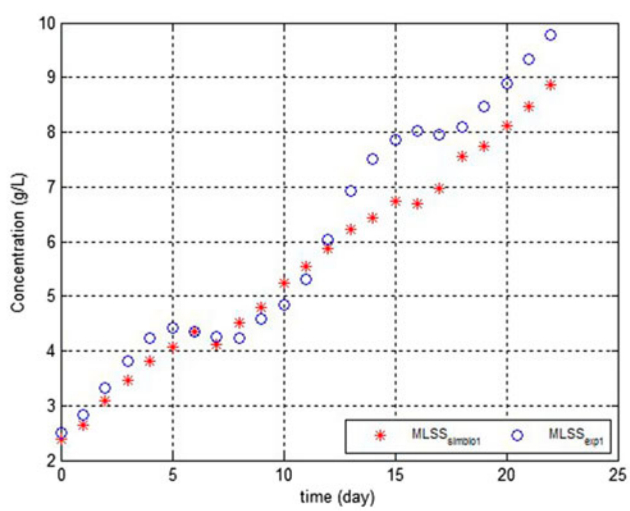

Fig. 8. Simulated (stars) and experimentally measured (open circles) MLSS values in the control bioreactor Bio1.

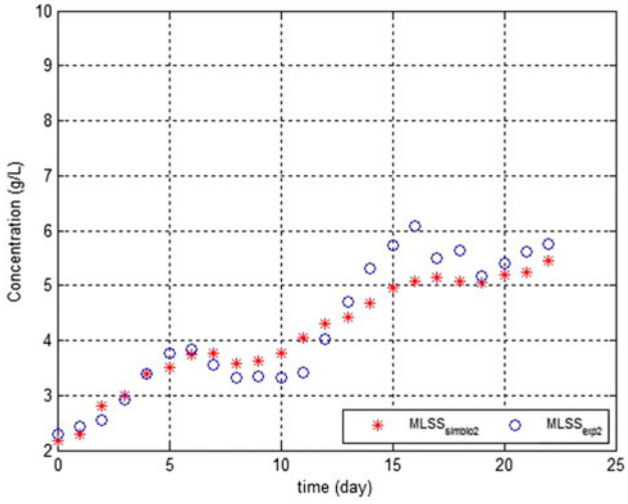

Fig. 9. Simulated (stars) and experimentally measured (open circles) MLSS values in the US treated bioreactor Bio2.

Table 8
Quantitative indicators of the goodness of the validation

Indicators→	R^2	RMSE	Cross-validation RMSE
MLSS in reactors↓	(–)	(–)	(–)
MLSS in Bio1	0.96	0.67	0.33
MLSS in Bio2	0.89	0.45	1.80

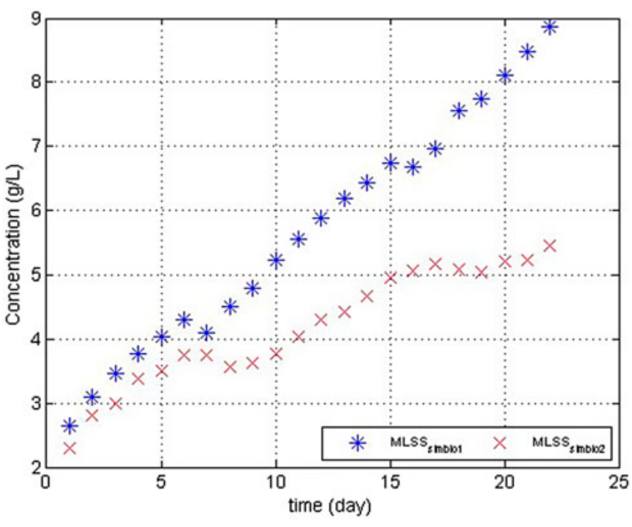

Fig. 10. MLSS simulation results in Bio1 and Bio2 at WWTP Haasrode.

Fig. 10 also depicts the accumulation of biomass in the two SBR tanks after 23 d of simulation to better infer the reduced biomass accumulation. Due to the ultrasonic disintegration, a much lower biomass (38.5% lower) concentration was observed in Bio2 than in Bio1, which is very close to the experimental data.

4. Conclusions

Based on the validation with real-life experimental data, the quality of the presented integrated model, combining biological wastewater treatment with ultrasound sludge disintegration of a part of the return sludge, is illustrated. The biological treatment is modeled by a classic ASM1 model in which a set of algebraic equations is integrated to quantify the instantaneous MLSS reduction and sCOD release. The results confirm a good prediction capacity of the integrated model. In the case study of Mechelen-Noord, the observed 42% less waste sludge production was well predicted, while also the industrial case study waste sludge reduction of 38.5% could be predicted. Given that the ultrasound treatment is shown to be very effective, the integrated model can now be exploited to look for the most optimal (read: least costly) operational settings with respect to, e.g. power intensity.

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