MODELLING OF AN ACTIVATED PRIMARY SETTLING TANK INCLUDING THE FERMENTATION PROCESS AND VFA ELUTRIATION.

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Abstract

A complete model of a primary settler including both sedimentation and biological processes is presented. It is a one-dimensional model based on the solids flux concept and the conservation of mass that uses the Takács model for the settling velocity, which is corrected by a compression function in the lower layers. The biological model is based on the ASM2 and enlarged with the fermentation model proposed by this research group. The settler was split in ten layers and the flux terms in the mass balance for each layer is obtained by means of the settling model.

A pilot plant has been operated to study the primary sludge fermentation and volatile fatty acids (VFA) elutriation in a primary settler tank. The model has been tested with pilot plant experimental data with very good results. It has been able to simulate the VFA production in the settler and their elutriation with the influent wastewater for all the studied experiments. The developed model is easily applicable to secondary settlers and thickeners, also taking into account biological activity inside them.

Keywords: primary clarifier model; sedimentation; settler; thickening; volatile fatty acids.

INTRODUCTION

It has been evidenced in many studies and practical experience that high content of readily biodegradable chemical oxygen demand (RBCOD), specially volatile fatty acids (VFA), in the influent waste water is

needed to promote enhanced biological phosphorus removal (EBPR) in an activated sludge process with anaerobic/aerobic cycles [1, 2]. When the influent wastewater contains low concentrations of VFA, it can be increased by external substrate addition such as acetate, or it can be also produced in the waste water treatment plant (WWTP) itself by fermenting the primary sludge. The use of dissolved fermentation products results in higher denitrification rates than with synthetic substrates, and in a similar ratio of phosphate release to substrate uptake in EBPR processes [3].

Several schemes of operation have been reported for VFA production from primary sludge fermentation [2, 4]. One of the simplest configurations for fermentation and elutriation of primary sludge consists in allowing settled raw sludge solids to accumulate in the bottom of the primary settler tanks (PST) and recycling partially this sludge to elutriate the fermentation products out of the sludge. The rest of the accumulated sludge is purged to avoid the VFA consumption by methane formation.

On the other hand, most of the proposed settler models to date do not consider any biological reactions taking place inside them, simulating only the suspended solids behaviour. However, it is a well-known fact that, in certain situations some biological phenomena take place in the settlers. Many examples of these situations have been reported by several authors. The most important biological processes taking place in the settlers are denitrification in secondary settlers, hydrolysis and ammonification in primary settlers and prefermentation of primary sludge to produce VFA in primary settlers. Although it exists some references about coupling biological processes and sedimentation processes [5], they are simplified models or they are not compatible with generally applied models such as Activated Sludge Model No. 1 and No. 2 (ASM1 and ASM2) [6, 7]. Only a few settler models use the same variables as those defined in ASM1 [8, 9]. However, these models do not consider the fermentation of primary sludge inside the settler or assume that there is no biological activity in the settler.

The aim of this work is to develop and validate a new model for these processes to simulate the VFA production and to study different control strategies for the entire plant nutrient removal processes

(nitrogen and phosphorus). In this paper, a new model including both sedimentation and biological processes such as hydrolysis and acidification process is presented. This model is totally compatible with the ASM2 [7] and it includes also the fermentation model presented in [10]. It has been validated with experimental data obtained from a pilot plant site in the Carraixet WWTP in Valencia (Spain).

THE CLARIFIER MODEL

The developed model for the primary clarifier is a one-dimensional model based on the flux theory and the Takacs model for the settling velocity [11].

Accordingly to the flux theory, the total flux (J_T) of the total suspended solids (TSS) in the settler is the sum of the gravity settling flux (J_S) and the bulk flux (J_B), which results from the flow of the water into the settler.

$$J_T = J_S + J_B \qquad \text{(i)}$$

$$J_T = V_S \cdot X + V \cdot X \qquad \text{(ii)}$$

being X the TSS concentration.

The clarifier dynamical model is derived from a mass-balance applied to a small section (dh) of the settler (see figure 1).

$$-\frac{\partial X}{\partial t} = \frac{\partial (V_S \cdot X)}{\partial h} + \frac{\partial (V \cdot X)}{\partial h} + G_X \qquad \text{(iii)}$$

where the bulk velocity (V) is defined as

$$V = \begin{cases} V_U = \dfrac{Q_E}{A} & \text{if} \quad h > h_f \\ V_D = \dfrac{Q_R}{A} & \text{if} \quad h \le h_f \end{cases} \qquad \text{(iv)}$$

The generation term (G_X) represents the increase or decrease of TSS due to biological processes inside the settler. This term is obtained by means of the biological model, which provides the changes in concentrations of the biological components of the particulate material.

Equation (iii) can be solved by splitting up the settler into horizontal layers, discretizing it on these layers and considering each horizontal layer as a complete mixed reactor. So, the mass-balance for each layer (i) results

$$\frac{\Delta h_i \cdot \partial X_{n \to n+1}}{\partial t} = \left[V_{U,i-1} \cdot X_{i-1} - V_{U,i} \cdot X_i + V_{S,i+1} \cdot X_{i+1} - V_{S,i} \cdot X_i + G_{X,i} \cdot \Delta h_i \right]_n \quad \text{for } i > f \qquad \text{(v)}$$

$$\frac{\Delta h_i \cdot \partial X_{n \to n+1}}{\partial t} = \left[V_{D,i-1} \cdot X_{i-1} - V_{D,i} \cdot X_i + V_{S,i+1} \cdot X_{i+1} - V_{S,i} \cdot X_i + G_{X,i} \cdot \Delta h_i \right]_n \quad \text{for } i < f \qquad \text{(vi)}$$

$$\frac{\Delta h_i \cdot \partial X_{n \to n+1}}{\partial t} = \left[\frac{Q_F}{A_f} \cdot X_F - \left(V_{U,i} + V_{D,i} \right) \cdot X_i + V_{S,i+1} \cdot X_{i+1} - V_{S,i} \cdot X_i + G_{X,i} \cdot \Delta h_i \right]_n \quad \text{for } i = f \qquad \text{(vii)}$$

where f is the feed layer of the settler.

The sludge is assumed to be present in the form of flocs with the settling velocity obtained by means of the TSS concentration. In each layer, all suspended components in the model that form the particulate material of the flocs are propagated through the settler with the same settling velocity (V_S), which is obtained by the settling model.

Stationary concentrations are obtained by solving a system of non-linear equations composed by the ten mass balance equations for the ten layers in which the settler is split (equations v to vii with the first term equal to zero).

Since biological model and settler model work with different variables (kg COD·m^{-3} and kg SS·m^{-3} respectively), conversion factors are needed to know the true mass (kg SS) for all particulate components of the biological model. A steady state solution for the settler can be obtained by an iterative procedure between the biological model and the settling model (figure 2). The settler model gives the mass flux between the layers, which are the inputs and outputs for each layer.

With this information, and applying the biological model, new values of the biological components are obtained. Then, with these values, new TSS concentrations are obtained for each layer, which are used by the settling model to obtain new fluxes of particulate material. The iterations terminate when the differences for all components are sufficiently small in two consecutive iterations.

Hence, the settling model provides the mass transport from one layer to another and the biological model provides the generation term for each component in the model. The biological model is based on the ASM2 [7] and the fermentation model [10].

Because of the shape of the solids flux function obtained when it is applied to a continuous sedimentation tank in both, clarification and thickening zones (figure 3), a limiting flux concept has been implemented in the settling model to obtain the solids fluxes between the settler layers. Hence, the total flux of solids along the settler is obtained as [9],

$$J_{T,i} = \begin{cases} \min\limits_{X \in [X_{i-1}, X_i]} \left(V_S(X) \cdot X - \dfrac{Q \cdot X}{A_i} \right) & \text{if} \quad X_{i-1} \geq X_i \\ \max\limits_{X \in [X_i, X_{i-1}]} \left(V_S(X) \cdot X - \dfrac{Q \cdot X}{A_i} \right) & \text{if} \quad X_{i-1} < X_i \end{cases} \qquad \text{(viii)}$$

This equation ensures that the concentration of a certain layer (i) is not higher than that of the layer below (i-1) and avoids numerical instabilities when load is increased rapidly.

Settling model

The settling model considers all processes of sedimentation taking place in settlers and thickeners (flocculent settling, hindered settling and compression process). It is based on the settling function of Takács et al. [11] and the compression factor concept proposed by Härtel and Pöpel [12] and applied also by Otterpohl and Freund [5].

The settling velocity function incorporating the settleability of both dispersed and flocculated suspended solids is defined as [11],

$$V_S = \max\left\{0, \min\left[V_0', V_0 \cdot \left(e^{-r_h \cdot X^*} - e^{-r_P \cdot X^*}\right)\right]\right\} \qquad \text{(ix)}$$

where $X^* = X - f_{ns} \cdot X_f$ represents the settleable suspended solids concentration and $f_{ns} \cdot X_f$ represents the non settleable solids concentration in the influent wastewater, for which zero settling velocity is assumed. Settling parameters r_h and r_p are associated with hindered and flocculent settling respectively, and V_0 and V'_0 represent the maximum theoretical and practical settling velocity as they are defined in [11].

The compression factor function (Ω) is based on empiricism and is dependent on the sludge volume index (SVI), the height in the settler (h) and the feed solids concentration (X_f). The used function for this factor is based on that proposed by Otterpohl and Freund [5] and is defined as

$$\Omega = \frac{1 - B \cdot h_t^{-\left(1+\frac{2 \cdot SVI}{100+SVI}\right)}}{1 - B \cdot \left[\min(h, h_t)\right]^{-\left(1+\frac{2 \cdot SVI}{100+SVI}\right)}} \qquad \text{(x)}$$

with

$$B = -\left(\frac{100 + SVI}{SVI} + 1\right) \cdot h_C^{\left(1+\frac{2 \cdot SVI}{100+SVI}\right)} \qquad \text{(xi)}$$

$$h_t = \min(2 \cdot h_C , h_f) \qquad \text{(xii)}$$

$$h_C = \left(1 - \frac{1}{X_C \cdot r_h}\right) \cdot \left(\frac{X_f \cdot h_f}{X_C}\right) \qquad \text{(xiii)}$$

$$X_C = \frac{480}{SVI} \qquad \text{(xiv)}$$

In order to account for the compression processes taking place at the bottom of the settlers and thickeners, the settling flux is defined now as

$$J_S = \Omega(h) \cdot V_S(X) \cdot X \qquad \text{(xv)}$$

Hence, the settling flux (J_S) is smoothly reduced through the Ω function from a height somewhat below the inlet layer downwards and reaches zero at the bottom. This compression factor sets the settling flux to zero at the bottom of the settler and solves the boundary conditions inconsistency found with other models in the lower layer.

Biological model

The biological model is based on the ASM2 and the fermentation model proposed by Serralta et al. [10]. In order to be capable to simulate all possible operation conditions in a WWTP, the developed biological model considers the following groups of microorganisms: heterotrophs, autotrophs, phosphate accumulating organisms, acidogens, acetogens, acetoclastic methanogens and hydrogenotrophic methanogens.

In the primary sludge fermentation, methane production is minimised by maintaining a relatively short solids retention time and by allowing the pH to drop as VFAs are produced. So, the pH value is very important in this process. The developed model includes a systematic methodology that allows calculating the pH value [10].

Although only acidogenic bacteria are present in the studied system, the other groups of bacteria are included in the model because the final objective of this work is to develop a general model which should be able to simulate all possible processes taking place in settling tanks. So, this general model should be able to simulate for example the effect of a recirculation of settled secondary sludge to the inlet of the primary settler.

In this paper, only processes associated with acidogen organisms are presented. The processes associated with the rest of organisms groups are similar to that ones in ASM2 and the fermentation model. The stoichiometric parameters and reaction rate expressions are summarized in tables 1 and 2.

A surface-limited reaction (X_S/X_{ACID}) / (($K_{S,X}+X_S/X_{ACID}$) is assumed for the hydrolysis process. The process rate of biomass growth is assumed to depend on Monod kinetics for the substrate and nutrients (ammonia and phosphate). Oxygen, nitrate and product inhibitions are included in the kinetic expressions, so fermentation process is inhibited by a high acetic acid concentration and by the presence of oxygen and nitrate. The pH dependence is modelled with a combination of Monod and inhibition kinetics for pH $(10^{-pH}/(K_{S,pH}+10^{-pH}))\cdot(K_{I,pH}/(K_{I,pH}+10^{-pH}))\cdot 1/f_{pH}$ where f_{pH} accounts for the fact that at optimum pH the rate of fermentation process is the maximal growth rate of acidogenic bacteria. f_{pH} represents the value of the switch functions calculated at optimum pH:

$$f_{pH} = \frac{10^{-pHopt}}{K_{S,pH}+10^{-pHopt}} \cdot \frac{K_{I,pH}}{K_{I,pH}+10^{-pHopt}} \qquad \text{(xvi)}$$

Optimum pH can be obtained from values of $K_{S,pH}$ and $K_{I,pH,}$ being $pH_{opt}=\sqrt{K_{S,pH}\cdot K_{I,pH}}$. Enzymatic activity depends on pH value, so the pH dependence is also included in the hydrolysis process.

The most important differences between ASM2 model and the proposed biological model are the following:

- The proposed biological model considers that fermentation process (process number 8 in ASM2) is carry out by a separate group of heterotroph microorganisms (acidogens). These microorganisms grow anaerobically by fermentation of fermentable substrate (S_F). The use of a separate group of microorganisms can be justified by the low values of q_{fe} obtained in ASM2 calibrations by several authors [13].

- The pH dependence of microorganisms is modelled with an inhibition switch function of pH. Hence, the S_{ALK} component, which is used in ASM2 in order to obtain an early indication of possible low pH conditions, is not necessary in this model because pH is directly calculated.

MODEL VALIDATION

Materials and methods

A pilot plant was operated to study the primary sludge fermentation and VFA elutriation in a primary settler equipped with a sludge recirculation flow. It was fed with 40 $l \cdot h^{-1}$ of municipal raw wastewater coming from the degritter in Carraixet WWTP in Valencia, Spain. The flux diagram of the pilot plant is shown in figure 4. Design characteristics of the settler are shown in table 3.

The pilot plant was thermically isolated with 3 cm thick glass-fiber cover and the system was maintained in a constant temperature of 20 ± 1ºC.

Analytical methods

The analyses of total suspended solids (TSS), volatile suspended solids (VSS), COD, phosphorus and ammonium were performed in accordance with Standard Methods [14]. The total amount of volatile fatty acids and the carbonate alkalinity were measured by 4-point titration at pH 6.7, 5.9, 5.2 and 4.3 with 0.1M HCl and evaluated according to the method of Moosbrugger et al. [15]. Biological oxygen demand (BOD) was determined by pressure measurements using a WTW Oxitop Control 100 system. The pH was also measured at the inlet and the effluent of the settler. A perforated glass twig was used like a prospection probe in order to obtain the sludge blanket level in the settler.

Experimental data

The pilot plant was operated at two different solids retention time (SRT) and two different recirculation flow rates (RSFR) (see table 4). At such low solids retention time, only acidogenic bacteria can grow in the settler and no methanogenic processes was observed.

The average influent characteristics are shown in table 5 for the three steady states studied. These values were obtained from the ASM2 influent characterization [7], VFA analyses and suspended solids measurements. Acetate and propionate concentrations were obtained by means of VFA analyses and considering that they were in the same fractions proposed in the model for their generation from the fermentation of fermentable substrate (69.8 % of acetate and 30.2 % of propionate).

Model calibration

The settling parameters were obtained by simulation in order to get the best fit of both TSS concentration data in the settler outlets and measured sludge blanket height.

The SVI value obtained by simulation was lower than that obtained experimentally in the laboratory (50 $ml \cdot g^{-1}$). This difference can be explained by the conical shape of the settler, because the concentration is increased in the downward direction through the decrease in the cross-section [16]. Hence, the SVI obtained by simulation results in a lower value to achieve the high concentration observed in the pilot plant.

The biological model incorporates a large number of stoichiometric and kinetic parameters relating to all groups of microorganisms considered. However, since only acidogenic bacteria were considered to grow in the system, only these parameters were estimated in order to get the best fit of experimental data (see

table 7). For the rest of parameters, typical values recommended in ASM2 and the fermentation model [10] were assumed.

RESULTS AND DISCUSSION

Simulation results

For model verification purposes, the developed model has been implemented in the simulation software DESASS (Design and Simulation of Activated Sludge Systems). A steady state simulation was computed using average pilot plant influent characteristics during each period of operation as model inputs. The model predictions (using the calibrated parameters shown in tables 6 and 7 are presented in table 8).

The proposed model successfully characterizes the VFA generation in the settler for different SRTs and recirculation flow-rates. Results in table 8 show very good correspondence between model predictions and experimental data. As can be seen, the model accurately reproduces all the measured variables for all the experiments. Furthermore, the developed systematic methodology for calculating the pH value was able to predict the pH decrease due to VFA generation in the lower layers of the settler (see figure 5).

As can be seen in table 8, when SRT is increased, VFA production increases too due to the higher residence time of acidogenic bacteria in the settler. This trend has been accurately reproduced by the settler model. Furthermore, the settling model was able to predict successfully the total solids concentrations in the settler outlets as well as the sludge blanket height in all the experiments.

CONCLUSIONS

A new model of a primary settler including both sedimentation and compression processes has been developed. It has been tested with pilot plant experimental data with very good results. The proposed

model successfully characterizes the total solids concentrations and VFA generation in the settler for different SRTs and recirculation flow-rates by means of the adjustment of settling and biological parameters.

Experimental results show the effect of SRT and recirculation flow-rate on fermentation-elutriation process. When SRT is increased, VFA production increases too due to the higher residence time of acidogenic bacteria in the settler. Higher recirculation flow-rates result in higher VFA production too. This trends have been accurately reproduced by the settler model. Furthermore, the settling model is able to predict successfully the total solids concentrations in the settler outlets as well as the sludge blanket height.

Operating conditions studied in pilot plant show good results in VFA production witch made this operating scheme attractive to use in WWTPs to increase the influent VFA concentration to promote enhanced biological phosphorus removal.

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Table 1. Matrix with stoichiometric parameters related to the processes considered in this paper.

Process	S_F	S_A	S_{NH4}	S_{PO4}	S_I	X_I	X_S	S_{PRO}	S_{H2}	S_{CO2}	X_{ACID}	S_{totC}	S_{totH}
Hydrolysis of biopolymers (X_S)	$1-f_{SI}$		**	**	f_{SI}		-1			**		**	**
Acidogens growth to ferment soluble COD	$\frac{-1}{Y_{ACID}}$	$\left(\frac{1}{Y_{ACID}}-1\right)\cdot f_{Ac}$	**	**				$\left(\frac{1}{Y_{ACID}}-1\right)\cdot f_{Pro}$	$\left(\frac{1}{Y_{ACID}}-1\right)\cdot f_{H2}$	**	1	**	**
Decay of acidogens			**	**		f_{XI}	$1-f_{XI}$			**	-1	**	**

Table 2. Kinetic rate expressions for the processes considered in this paper.

Process	Kinetic expressions
Hydrolysis of biopolymers (XS)	$K_H \cdot \frac{K_{I,O2}}{K_{I,O2}+S_{O2}} \cdot \frac{K_{I,NO3}}{K_{I,NO3}+S_{NO3}} \cdot \frac{X_S/X_{ACID}}{K_{S,X}+X_S/X_{ACID}} \frac{10^{-pH}}{K_{S,PH}+10^{-pH}} \cdot \frac{K_{I,PH}}{K_{I,PH}+10^{-pH}} \cdot \frac{1}{f_{pH}} \cdot X_{ACID}$
Acidogens growth to ferment soluble COD	$\mu_{ACID} \cdot \frac{K_{I,O2}}{K_{I,O2}+S_{O2}} \cdot \frac{K_{I,NO3}}{K_{I,NO3}+S_{NO3}} \cdot \frac{S_F}{K_{S,F}+S_F} \cdot \frac{K_{I,A}}{K_{I,A}+S_A} \cdot \frac{S_{NH4}}{K_{S,NH4}+S_{NH4}} \cdot \frac{S_{PO4}}{K_{S,PO4}+S_{PO4}} \cdot \frac{10^{-pH}}{K_{S,PH}+10^{-pH}} \cdot \frac{K_{I,PH}}{K_{I,PH}+10^{-pH}} \cdot \frac{1}{f_{pH}} \cdot X_{ACID}$
Decay of acidogens	$b_{ACID} \cdot X_{ACID}$

Table 3. Design characteristics of the settler.

Diameter	0.5 m
Total height	0.9 m
Slope of conical part	173 %
Volume	112 L

Table 4. Operation conditions studied.

Experiment	SRT (d)	RSFR ($l \cdot h^{-1}$)
1	3.8	1.5
2	3.7	2.0
3	4.7	2.0

Table 5. Influent wastewater characteristics.

Influent Waste Water	Experiment 1	Experiment 2	Experiment 3
Influent flow rate ($l \cdot h^{-1}$)	40.0	40.0	40.0
Return sludge flow rate ($l \cdot h^{-1}$)	1.5	2.0	2.0
Waste sludge flow rate ($l \cdot h^{-1}$)	0.065	0.069	0.060
Solids retention time (d)	3.8	3.7	4.7
S_F (mg COD$\cdot l^{-1}$)	32.3	43.3	83.8
S_A (mg COD$\cdot l^{-1}$)	6.4	12.1	4.3
S_{PRO} (mg COD$\cdot l^{-1}$)	2.7	5.2	1.9
S_I (mg COD$\cdot l^{-1}$)	32.6	53.0	25.0
S_{NH4} (mg N$\cdot l^{-1}$)	34.6	37.7	34.5
S_{PO4} (mg P$\cdot l^{-1}$)	3.9	4.2	3.4
S_{ALK} (mg $CaCO_3 \cdot l^{-1}$)	8.4	8.4	8.7
X_I (mg COD$\cdot l^{-1}$)	119.0	48.0	80.7
X_S (mg COD$\cdot l^{-1}$)	149.0	301.0	186.3
X_{NV} (mg SS$\cdot l^{-1}$)	66.0	100.0	89.0
X_{TSS} (mg SS$\cdot l^{-1}$)	205.1	297.4	226.5
f_{ns} (%)	65	71	66
pH	7.7	7.7	7.7

Table 6. Settling parameters obtained by adjusting the model to experimental data.

Settling parameter	Value
SVI ($ml \cdot g^{-1}$)	21
V_0 ($m \cdot d^{-1}$)	425
V_0' ($m \cdot d^{-1}$)	350
r_h ($m^3 \cdot g^{-1}$)	0.00017
r_p ($m3 \cdot g^{-1}$)	0.001

Table 7. Stoichiometric and kinetic parameters related to processes carried out by acidogenic bacteria.

Parameter	Units	Value	Source
Hydrolysis			
K_H (Hydrolysis rate constant)	g COD· m^{-3}	43	Fitting
$K_{S,X}$ (half-saturation coefficient for particulate COD)		150	Fitting
$K_{S,pH}$ (half-saturation coefficient for pH)	mol $H^+ \cdot m^{-3}$	10^{-5}	[10]
$K_{I,pH}$ (Inhibition coefficient for pH)	mol $H^+ \cdot m^{-3}$	$6.3\ 10^{-4}$	[10]
Acidogenic Bacteria			
Y_{ACID} (Yield coefficient)		0.15	[17]
f_A (fraction of fermented S_F transformed to acetate)		0.58	[17]
f_{PRO} (fraction of fermented S_F transformed to propionate)		0.25	[17]
f_{H2} (fraction of fermented S_F transformed to hydrogen)		0.17	[17]
μ_{ACID} (maximum specific growth rate)	day^{-1}	2.14	Fitting
b_{ACID} (rate constant for lysis)	day^{-1}	0.33	Fitting
$K_{S,F}$ (half-saturation coefficient for fermentable substrate)	g COD· m^{-3}	15	Fitting
$K_{I,O2}$ (Inhibition coefficient for oxygen)	g COD· m^{-3}	0.2	[7]
$K_{I,NO3}$ (Inhibition coefficient for nitrate)	g N· m^{-3}	0.5	[7]
$K_{I,A}$ (Inhibition coefficient for acetate)	g COD· m^{-3}	6500	[10]
$K_{S,NH}$ (half-saturation coefficient for ammonia)	g N· m^{-3}	0.05	[7]
$K_{S,P}$ (half-saturation coefficient for phosphorus)	g P· m^{-3}	0.01	[7]
$K_{S,pH}$ (half-saturation coefficient for pH)	mol $H^+ \cdot m^{-3}$	10^{-5}	[10]
$K_{I,pH}$ (Inhibition coefficient for pH)	mol $H^+ \cdot m^{-3}$	$6.3\ 10^{-4}$	[10]

Table 8. Comparison of simulated with experimental results

	Experiment 1 (SRT = 3.8 d)				**Experiment 2 (SRT = 3.7 d)**				**Experiment 3 (SRT = 4.7 d)**			
	Underflow		Effluent		Underflow		Effluent		Underflow		Effluent	
Measured Variables	Exper. value	Simul. value	Exper. value	Simul. value	Exper. value	Simul. value	Exper. value	Simul. value	Exper. value	Simul. value	Exper. value	Simul. value
TSS (mg·l^{-1})	38290	38060	134	133	38986	38713	210	213	42533	42009	146	149
% VSS	63.4	66.0	68.0	66.2	62.0	64.0	66.2	64.2	57.8	57.8	60.3	58.0
Sol. COD (mg·l^{-1})	588	593	94.5	94.1	715	762	162	146.3	720	735	140	145.6
Total COD (mg·l^{-1})	48280	48753	265	263	44640	44371	391	387	47010	47339	312	311
VFA (mg·l^{-1})	448.2	432	21.1	25.4	536.4	521	37.7	42.5	575.0	572	31.6	34.6
Ammonia (mg·l^{-1})	58.3	58.2	35.4	35.5	96.1	97.7	41.5	40.7	98.7	98.3	38.5	37.7
Phosphate (mg·l^{-1})	8.2	8.2	4.3	4.1	8.7	8.9	4.5	4.4	10.8	11.3	4.1	3.8
pH	*	6.18	7.59	7.48	*	6.3	7.56	7.45	*	6.24	7.56	7.43

* Non-available data.

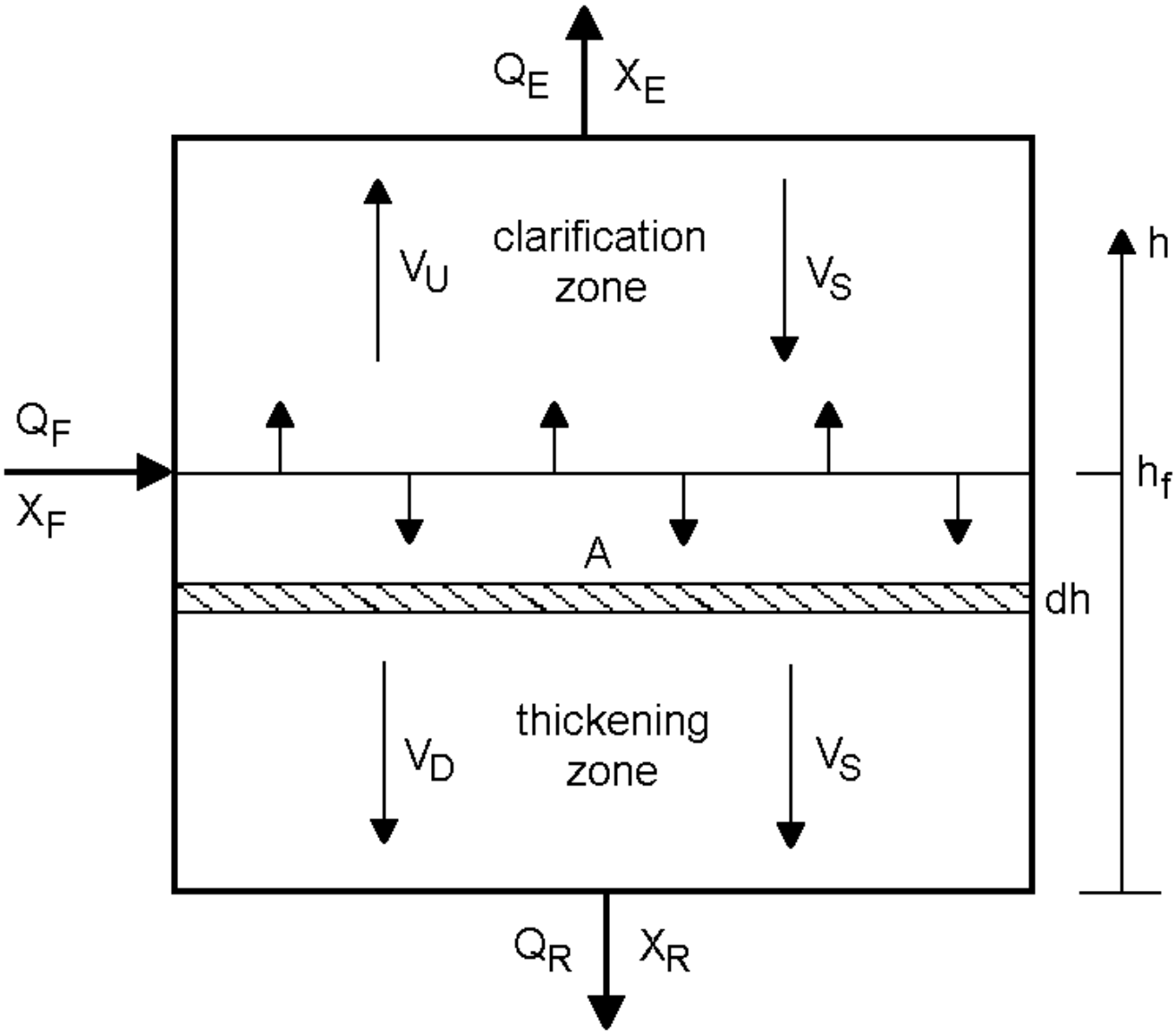
Figure 1. One-dimensional approach of the settler.

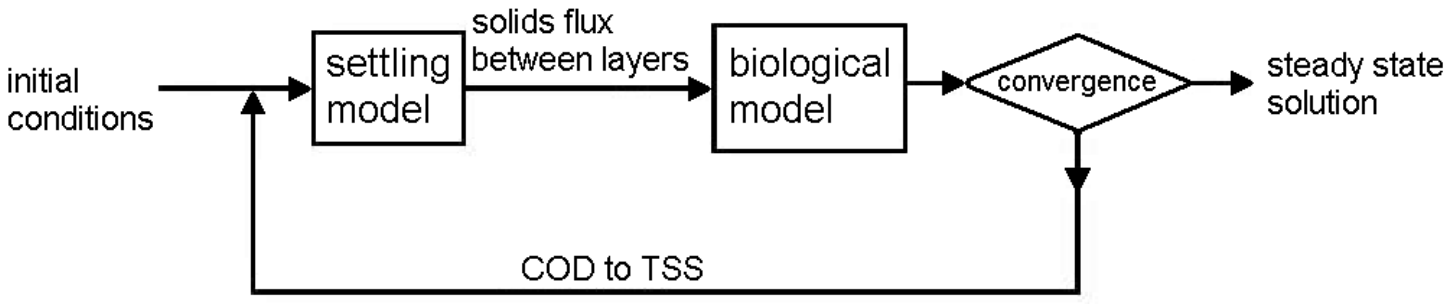
Figure 2. Flux diagram of the iterative process.

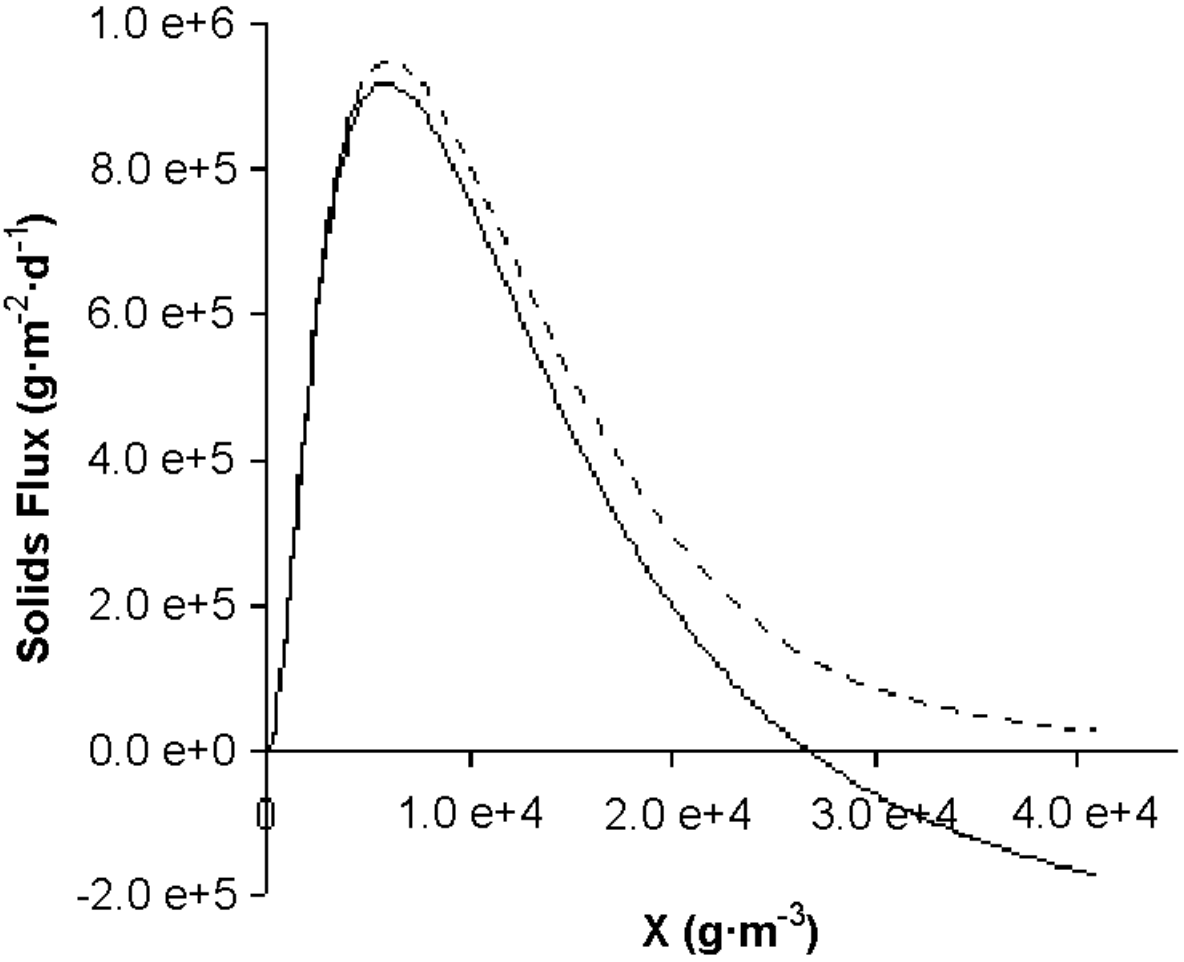
Figure 3. Solids total flux curves in clarification zone (solid line) and thickening zone (dotted line) of the primary clarifier. Figure (a) shows curves for high concentration values and figure (b) shows curves for low concentration values. Negative values of fluxes indicate that solids flow is directed upwards.

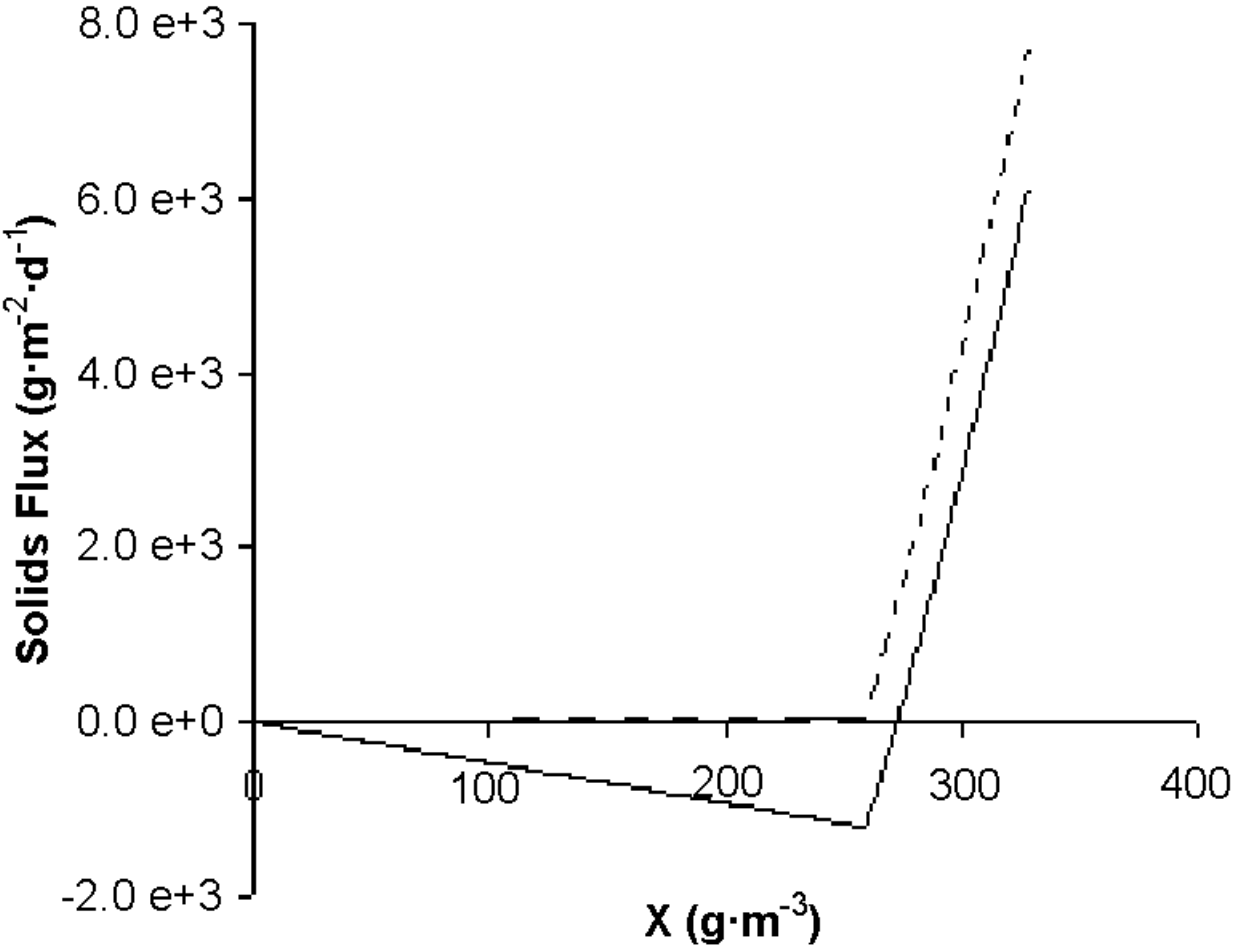
Figure 4. Flux diagram of the pilot plant.

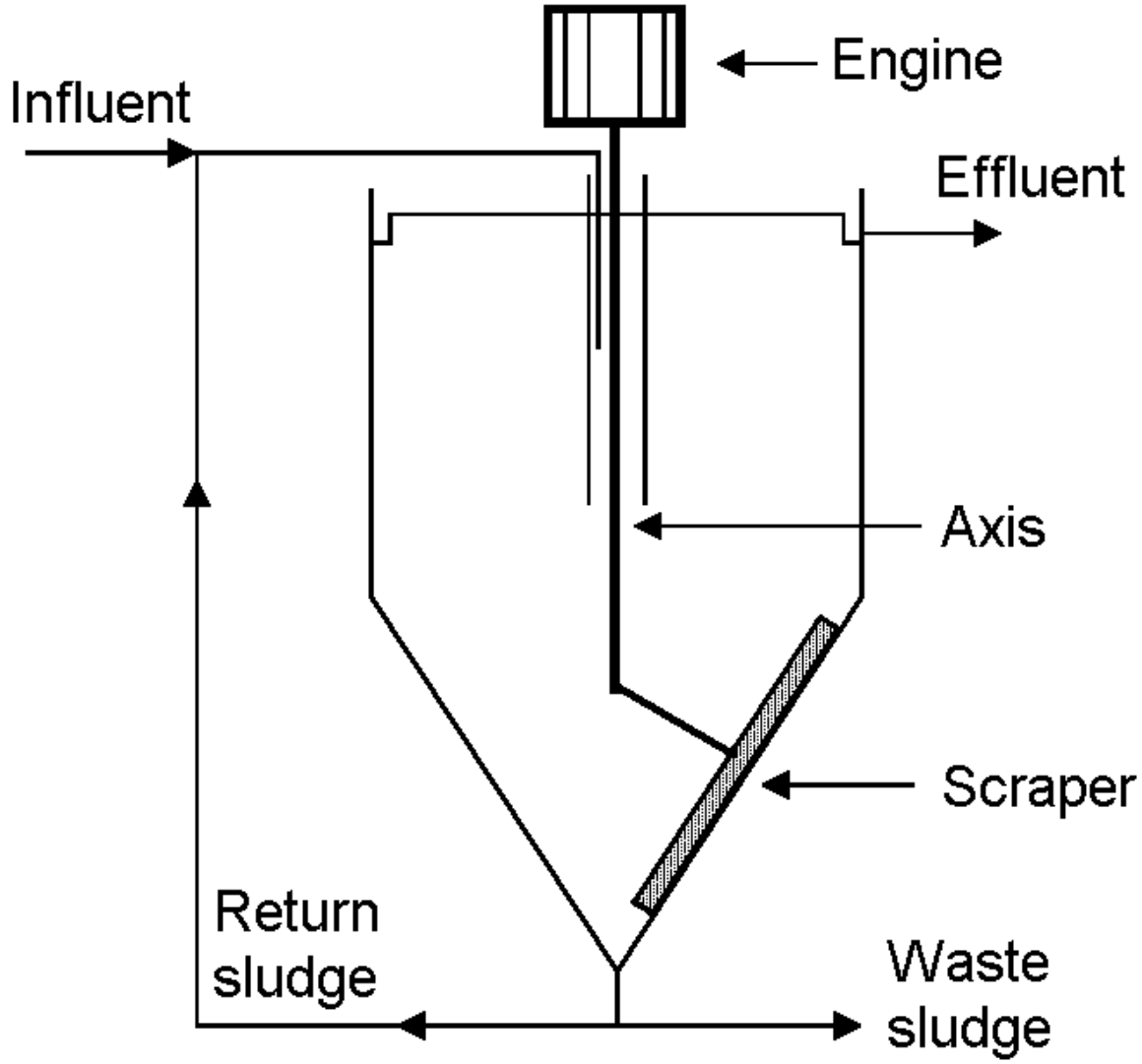
Figure 5. Settler concentration profiles of the VFA and pH in steady state.

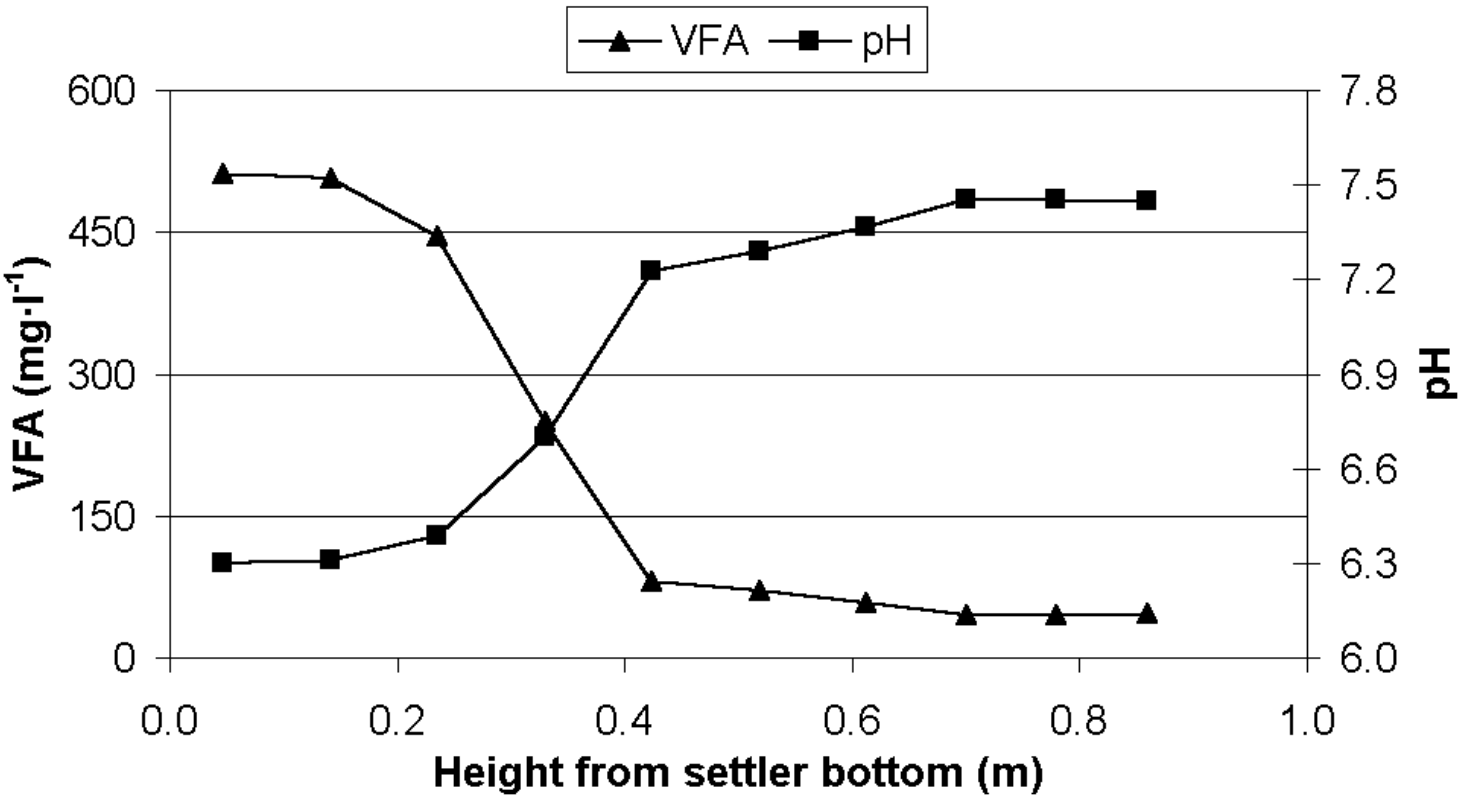

Q_E
X_E
V_U
clarification zone
V_S
h
Q_F
X_F
h_f
A
dh
V_D
thickening zone
V_S
Q_R
X_R


initial
conditions
settling
model
solids flux
between layers
biological
model
convergence
steady state
solution
COD to TSS


1.0 e+6
8.0 e+5
6.0 e+5
4.0 e+5
2.0 e+5
0.0 e+0
-2.0 e+5
0
1.0 e+4
2.0 e+4
3.0 e+4
4.0 e+4
Solids Flux (g·m-2·d-1)
X (g·m-3)


8.0 e+3
6.0 e+3
4.0 e+3
2.0 e+3
0.0 e+0
-2.0 e+3
Solids Flux (g·m-2·d-1)
0
100
200
300
400
X (g·m-3)


Engine
Influent
Effluent
Axis
Scraper
Return
sludge
Waste
sludge


VFA
pH
600
450
300
150
0
7.8
7.5
7.2
6.9
6.6
6.3
6.0
VFA (mg·l-1)
pH
0.0
0.2
0.4
0.6
0.8
1.0
Height from settler bottom (m)