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Activated Sludge with Total Solids Retention: Modified-ASM1 Modelling and Simulation

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Abstract: There are many new strategies put forward for minimizing excess sludge generation in biological wastewater treatment. Some of them were developed within the context of dynamic activated sludge modelling (ASM). A number of means can be used to eliminate the traditional waste activated sludge flow and the build-up of inert solids in the aeration tanks. This includes the use of fine screens to remove the inert particulate organic fraction (X_i), hydrocyclones to lower the inorganic suspended solids (ISS), and different kinds of on-line digesters to further biodegrade the endogenous residues (X_p), via the return activated sludge line (RAS). In this research, a model and a simulation program was developed, which was able to mimic the apparent behavior of such activated sludge variants with low-solids-production (LSP-AS). The model is an extended ASM1 assuming a small first order biodegradation constant for X_p ($k_{XP} = 0.007 \text{ d}^{-1}$), and black boxes representing the X_i and ISS inerts removal. The simulations depicted the way the different solids components build up in the aeration tanks, when traditional activated sludge (C-AS) is operated at very high solids retention times ($>100 \text{ d}$). The simulations showed that the C-AS process could hypothetically be replaced by LSP-AS variants with similar levels of active biomass and mixed liquor total suspended solids. With k_{XP} of about 0.007 d^{-1} and for the studied case, at least 2% (and 6%) of the RAS flow must be sieved (and digested, respectively), to avoid the accumulation of X_i , ISS and X_p . Also, the size of the on-line digester will be about twice the volume of the aeration tank.

Keywords: Aquasim; ASM1; endogenous residues; inerts; minimization.

1. INTRODUCTION

Increasingly, new concepts are put forward to develop modified activated sludge variants with low solids-production (LSP-AS) or total-solids retention. The proposed methods seek to reduce the generation of solids from the source, inside the water treatment lines (Low and Chase, 1999). Different authors claim sludge reduction up to 60% for the LSP-AS process (Novak et al., 2007; Johnson et al., 2008; Troiani et al., 2011), compared to traditional activated sludge process (C-AS).

There are many new strategies put forward for minimizing excess sludge generation in biological wastewater treatment. Some of them were developed within the context of research on dynamic activated sludge modelling (ASM1, 2 and 3; Henze et al., 2000). Based on these models, the main components of the biological secondary sludge are made up by heterotrophic biomass (X_H), endogenous residues from decay (X_P), particulate inert organic matter and inorganic suspended solids (X_i and ISS). There are many LSP-AS processes known under different names. The principle of some of them is to eliminate the traditional waste activated sludge stream (WAS), and to selectively remove the three "inert" fractions (X_i , ISS and X_p), which otherwise would accumulate in the aeration tanks. When the traditional WAS, as known as far, is drastically reduced ($\text{SRT} > 100 \text{ d}$) or totally cancelled (total solids-retention), alternative solid wasting or degradation are needed. In the the CannibalTM process (Novak et al., 2007; Johnson et al., 2008), part of the Return Activated Sludge flow (RAS) is passed through fine sieves for removing X_i (typically, toilet paper and hairs, Ruiken et al., 2011) and through hydrocyclones for grit removal (ISS, Mansour-Geoffrion et al., 2010); an on-line digester installed in the RAS line is then used to further biodegrade the endogenous residues, X_p ,

considered before as completely inert (Ramdani et al. 2012). Literature on modelling and simulation of the LSP-AS is very scarce. Previously, Johnson et al. (2008) reported modelling work on the Cannibal™ process using a home-built program based on ASM2d model. ASM2d was modified by adding a new process, namely the anaerobic hydrolysis of the endogenous biomass products (X_P) to particulate biodegradable fraction (X_S). Ultimately, Jones et al. (2007), and then Ramdani et al. (2012), proposed a first order model for the decay of X_P , finding a rate constant k_{XP} of about 0.007 d^{-1} . Knowing the order of value of the degradation rate of X_P is a step forward for evaluating the feasibility of total sludge retention processes, which means operating activated sludge processes practically without wastage ($\text{SRT} > 100 \text{ d}$).

The objective of this research was to develop a modified-ASM1 based model that is able to mimic the behavior of LSP-AS processes, and evaluate the reaction volumes and flow needs of the extra-processes. The software Aquasim, known for its flexibility, was used (Reichert et al., 1998; Fall et al., 2007).

2. MATERIAL AND METHODS

2.1 Wastewater Treatment Plant case (WWTP).

The case studied initially is a conventional activated sludge plant with a flow rate of $10,000 \text{ m}^3/\text{d}$. The operational data are shown in Table 1. The influent contained 18 mg/L ISS (inorganic suspended solids) and 300 mg/L total COD. All the input parameters required to perform ASM1 simulations are given on Table 2.

Table 1: Flow rates and dimensions of the wastewater treatment plant

| Operational Data | Symbols | Values | Units |
|--------------------------------|----------------------|--------|-----------------------|
| Influent Flow rate | Q_{in} | 10,000 | m^3/d |
| RAS flow | Q_{rec} | 3,300 | m^3/d |
| Temperature | T | 20 | $^{\circ}\text{C}$ |
| Sludge retention time (Design) | SRT | 15 | d |
| Aeration tank volume | V_{Reactor} | 6000 | m^3 |
| Settler Volume | V_{Settler} | 400 | m^3 |

Table 2: Characteristics of the influent (ASM1 nomenclature)

| Components | Symbol | Valor | Units |
|---|-----------|-------|---------------------------|
| Inert soluble organic matter | S_I | 20 | $\text{g COD}/\text{m}^3$ |
| Readily biodegradable organic matter (soluble) | S_S | 70 | $\text{g COD}/\text{m}^3$ |
| Inert particulate organic matter | X_I | 40 | $\text{g COD}/\text{m}^3$ |
| Slowly biodegradable organic matter (particulate) | X_S | 170 | $\text{g COD}/\text{m}^3$ |
| Heterotrophic active biomass | X_H | 0 | $\text{g COD}/\text{m}^3$ |
| Autotrophic active biomass | X_A | 0 | $\text{g COD}/\text{m}^3$ |
| Biomass residues from lysis | X_P | 0 | $\text{g COD}/\text{m}^3$ |
| Dissolved oxygen (D.O.) | S_{Ox} | 0 | $\text{g COD}/\text{m}^3$ |
| Nitrites and Nitrites ($\text{NO}_2 + \text{NO}_3$) | S_{NO} | 0 | $\text{g N}/\text{m}^3$ |
| Ammonium nitrogen ($\text{N}_{\text{NH}_4^+} + \text{N}_{\text{NH}_3}$) | S_{NH} | 18 | $\text{g N}/\text{m}^3$ |
| Soluble biodegradable organic nitrogen | S_{ND} | 5 | $\text{g N}/\text{m}^3$ |
| Particulate biodegradable organic nitrogen | X_{ND} | 10 | $\text{g N}/\text{m}^3$ |
| Alkalinity | S_{ALK} | 5 | Mol/m^3 |
| Inorganic Suspended Solids (=TSS-VSS) | ISS | 18 | $\text{g TSS}/\text{m}^3$ |

To simulate the modified activated sludge variant (LSP-AS), a sieve, a hydrocyclone and a digester were inserted in the RAS line. Initially, the volume of the on-line digester unit (RAS-DU unit) was 1500 m^3 with RAS inflow of $100 \text{ m}^3/\text{d}$, in conformity with the design criteria of 15 d SRT suggested by Johnson et al. (2008). Concerning the physical unit processes, at the beginning, the flow fed to the hydrocyclone and screen line was set at 10% of the RAS flow; it was increased latter according to the desired levels of X_I and ISS in the aeration tank.

2.2 Mathematical modelling

The simulation program was developed in Aquasim, based on ASM1 (Henze et al., 2000). It has been modified by adding a new process for the aerobic degradation of the endogenous residues X_P , to X_S , in the digester (Table 3). Based on recent researches (Ramdani et al., 2012; Jones et al., 2007; Sperandio et al., 2013), the first order constant of X_P decay was set to $k_{XP} = 0.007 \text{ d}^{-1}$. For the other 8 processes of the ASM1, the default values were used (Henze et al., 2000). The dissolved oxygen concentration was made equal to $S_{Ox} = 2 \text{ mg/L}$ in the reactors.

Table 3: Definition of the additional processes used to extend the ASM1

| Processes ↓ | Components → | X_P | X_S | X_J | Rates |
|---|--------------|--------|--------|--------|--------------------|
| 1. Degradation of X_P | | -1 | +1 | - | $k_{XP} \cdot X_P$ |
| 2. Activated sludge wasting (WAS) | | $-X_P$ | $-X_S$ | $-X_J$ | $1/\text{SRT}$ |
| k_{XP} : decay constant (d^{-1}). X_J : one column for ISS and for each of the others particulate components of the ASM1 (X_I , X_{ND} , etc). SRT: retention time. | | | | | |

As a flexible option in Aquasim, the WAS flow was represented as a simple reaction that remove mixed liquor solids directly from the aeration tank (Table 3). The respective concentrations of the main sludge fractions (X_H , X_I , X_P , ISS), the total sums (MLVSS, MLTSS, MLCOD) and the observed yield (Y_{obs}) were calculated as function of the SRT. Different known ratios were used to be able to convert the concentrations from VSS, to TSS and COD, and vice-versa. The considered values were the following: $ic_{Vbio} = 1.42 \text{ mg COD/mg VSS}$ (for X_H , X_P , X_A , X_S); $ic_{Vinfluent} = 1.50 \text{ mg COD/mg VSS}$ (for X_I from the influent); $iv_{tbio} = 0.92 \text{ mg VSS/mg SST}$ (for X_H , X_P , X_A).

2.3 Process diagram as implemented in Aquasim

The flow sheet of the LSP-AS process was configured in Aquasim by defining the compartments (CSTR tanks) and links, as in Figure 1. The sludge return line (RAS) was modified by connecting two bifurcations transporting the concentrated solids, to the digester (RAS-DU) on one side, and to the physical treatments on the other (screen and hydrocyclone). The part of flow deviated were set through the fractions $frQ\text{-to-RAS-DU}$ and $frQ\text{-to-Sc-Hc}$, defined with respect to the total RAS flowrate from the settler (Q_{RAS} , Table 1). When $frQ\text{-to-RAS-DU}$ and $frQ\text{-to-Sc-Hc}$ are set to 0, the process becomes a traditional activated sludge (C-AS).

Black boxes were defined in Aquasim to simulate the physical processes as a point of material separation (settler, screen and hydrocyclone, Figure 1). The settler point-model was set with 100% removal efficiency (Eff-sedim). For the screen (SC) and Hydrocyclone (HC), selective separation of the solids was obtained by defining three types of efficiencies, depending on the types of solids: X_I removal efficiency (Eff_ X_I); ISS removal efficiency (Eff_ISS); Efficiency on the biological materials X_H , X_P , X_S and X_A (Eff_bio). Eff_bio was set to 0%, while Eff_ X_I and Eff_ISS were fixed at 80 and 0% in the sieve, against 0 and 80 % at the hydrocyclone (HC).

The final program implemented in Aquasim was endowed with a high flexibility, to allow its use to gradually explore different scenarios, ranging from conventional activated sludge process (C-AS), to complete sludge retention (LSP-AS variant). Extended aeration C-AS may be simulated, just by closing the valves ($frQ\text{-to-RAS-DU}$ and $frQ\text{-to-Sc-Hc} = 0$) and changing the SRT to 25 days. To begin the mutation toward a low sludge production process (LSP-AS), first change SRT to 150 d. To simulate the removal of X_I and ISS through the sieve and HC, set also $frQ\text{-to-Sc-Hc}$ at 0.1 (10% of the RAS).

The way by which the digester is added, to be able to degrade X_P , is by fixing $frQ\text{-to-RAS-DU} = 0.0303$ (or 3.03% of the RAS flow, as a first scenario). Latter, several other scenarios were tested with different digester volumes, HRTs and inflows.

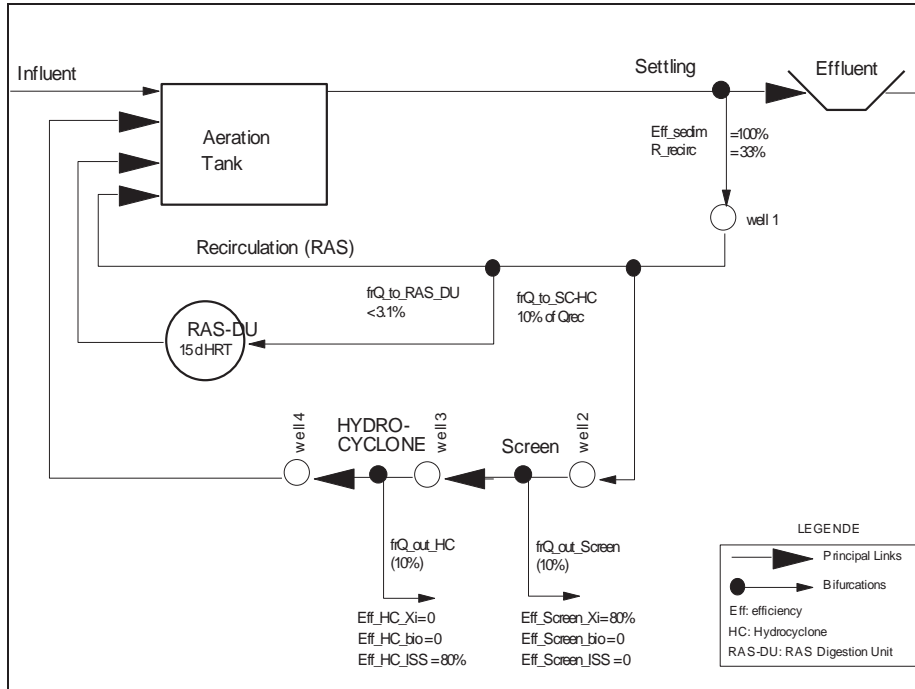


Figure 1: Diagram implemented in Aquasim to simulate the LSP-AS process

3. RESULTS AND DISCUSSION

3.1 Sludge production of the C-As process, as function of SRT

Figure 2 shows the composition of the C-AS mixed liquors at different SRT.

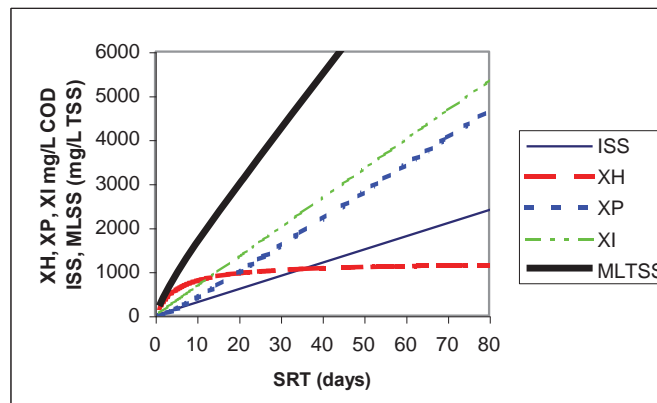


Figure 2: Mixed liquor composition of the C-AS process

From a certain residence time (> 20 d), the concentration of active biomass (X_H) reaches a plateau, which is dictated by the amount of substrate available in the influent. However, unlike the active biomass, the MLTSS continue to increase sharply with the SRT, due to the continuing accumulation of inerts in the mixed liquor (X_I , X_P , ISS). Functional requirements in activated process processes operated with low active biomass wasting are to minimize the amount of putrescible wasted sludge, while maintaining the mixed liquor concentrations at acceptable levels. The challenge would be to reach a selective removal or destruction of the components X_I , X_P , and ISS.

3.2 Simulation of the C-AS process, from 25 to 150 d SRT

Figure 3 shows the results of the simulations for the conventional activated sludge (C-AS) at 25 d SRT (extended-aeration), and then at 150 d (which in practice represents a hypothetical process operated without purging, i.e. no WAS). The area of interest is where the curves reach the steady state plateau.

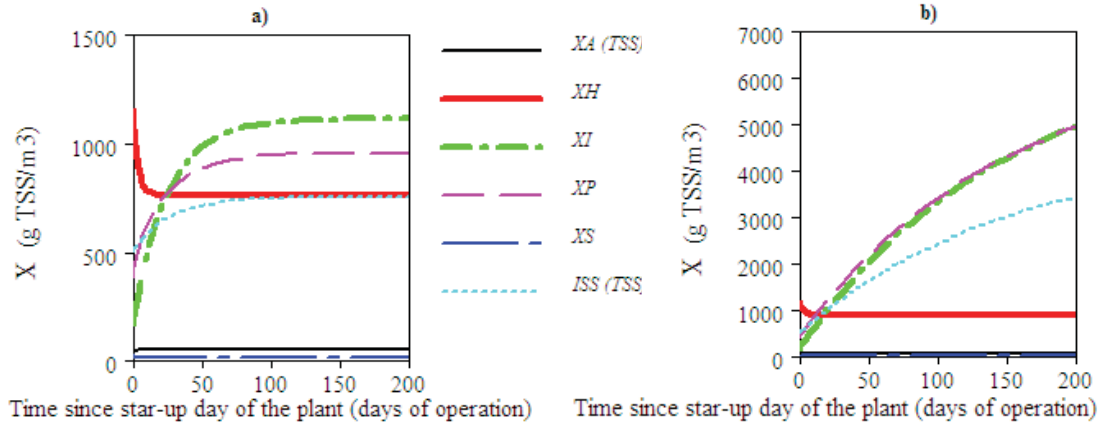


Figure 3: Mixed liquor composition at 25 d SRT (left) and at 150 d (right)

At 25 days SRT, the conventional activated sludge process works with concentration levels that are stable and acceptable, for all the mixed liquor components (Fig. 3 left, 3600 mg/L MLTSS and 750 mgTSS/L active biomass X_H). At 150 d SRT (Fig. 3 right), the active fraction is 890 mg / L TSS, not too different from the previous value (at 25 d). In contrast, X_I , X_P and ISS , and thereby the MLTSS in the mixed liquor, tend to accumulate, reaching at the end unsustainable high levels (> 10,000 mg/L, Fig. 3 right). From this moment, it seems clear that all C-AS that claim to be able to run in complete solid retention need additional processes to remove the excess X_I , X_P and ISS (not necessarily X_H).

3.3 Simulation of the effects of the screen and hydrocyclone.

At 150 d SRT (i.e. practically, with the WAS valve closed), when the screen and hydrocyclone are mounted, the inert solids levels drops abruptly to around 250 mg/L, with a flow fraction lower than 10% (of the RAS flow). As shown by Figure 4, the concentration of X_I and ISS in the reactor may be lowered at the same values or less, of that existing in standard C-AS operated without sieves at 25 d SRT (1110 mg/L X_I and 750 mg/L ISS).

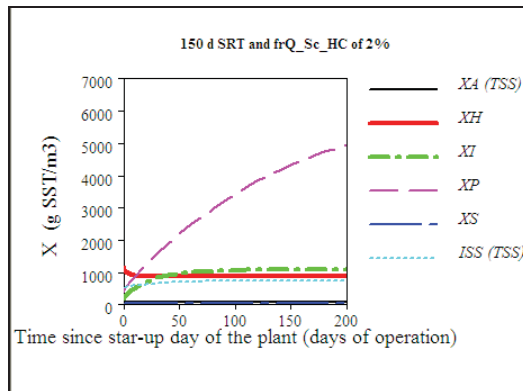


Figure 4: X_I and ISS under control in the aeration tank

An frQ-to-Sc-Hc of 2% (or 63 m³/d) applied to the LSP-AS process, operated at 150 days SRT (closed WAS), is enough to achieve the above desired levels. All the fractions (X_i , ISS, X_H , X_A and X_S) are now controlled (Figure 4) to a stable and acceptable level, except X_P that would continue to accumulate for the moment (not yet treated).

3.4 Simulation of the degradation of X_P in the on-line digester

By installing an aerobic digester (RAS-DU) through the return activated sludge line of the LSP-AS process, what is sought is to prevent the accumulation of X_P and maintain their concentration at an acceptable level. From a theoretical point of view, it is possible to estimate the X_P removal efficiency that will be reached in the RAS-DU itself. In general, assuming a 1st order kinetic rate law and assimilating the digester as completely stirred tank reactor (CSTR), the relationship between the hydraulic residence time (HRT) and efficiency (E) of removal of X_P , between the inlet and outlet of the digester, is given by equation (1).

$$E = \frac{HRT * k_{XP}}{(1 + HRT * k_{XP})} \quad (1)$$

E: efficiency for a given HRT, as a fraction; k_{XP} : first order constant (d⁻¹).

Equation (1) allows calculating the X_P removal efficiency that can be reached with a k_{XP} magnitude value of about 0.007 d⁻¹, as suggested in many studies (Ramdani et al., 2012; Jones et al., 2007). For 15 days HRT, the value of E is 0.095 (or 9.5%), against 30% at 60 days. Also, for each HRT (and efficiency so), the required volume can be calculated for different flow rates scenarios (frQ-to-RAS-DU,). Different combinations of flow rates and digester volumes were tested in the simulator.

Beyond the efficiency in the digester, the final response of interest from the simulations is the level of X_P that is reached in the aeration tank (between 3450 and 565 mg/L TSS, for the different scenarios tested). The LSP-AS scenarios that allow lowering these levels, up to near those of a standard C-AS satisfactorily operated at 25 SRT, are those reported in Table 4 (final residual X_P around 950 mg/L TSS). The volume of the RAS-DU unit for the best scenarios was between 10,000 and 15,000 m³, which is 1.7 to 2.5 times the volume of the aeration tank, or 3 to 5 times the volume of an off-line stabilization digester.

Another important aspect in the choice of the most viable alternatives is the impact of the on-line digester and its long HRTs, on the active biomass fraction X_H (Table 4). More biomass decay will result in the RAS-DU unit. X_H registered a sharp drop in scenarios 3 and 4 (350 and 470 mg/L), compared to the value of 750 mg/L TSS that was prevailing in the reference scenario (C-AS at 25 d SRT). Between the other two remaining scenarios, the digester option 2 seems to be the best compromise (shorter HRT, 60 d, and smaller volume). With scenario 2, the final levels of X_P and MLTSS in the aeration tank are under control now (about 900 mg/L TSS).

Table 4: Heterotrophic biomass (X_H) and MLTSS conc. in the aeration tank

| | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 | Reference |
|---|----------------------|----------------------|---------------------|---------------------|--------------|
| frQ-to-RAS-DU (%) => | 3.03% | 6% | 10% | 20% | no digester |
| HRT of digester | 150 d | 60 d | 30 d | 15 d | C-AS process |
| Digester volume | 15000 m ³ | 11880 m ³ | 9900 m ³ | 9900 m ³ | 25 d SRT |
| Concentrations (mg/L TSS) in the aeration tanks | | | | | |
| X_P | 991 | 914 | 970 | 930 | 950 |
| X_H | 680 | 565 | 473 | 350 | 755 |
| MLTSS* | 3500 | 3300 | 3260 | 3070 | 3600 |
| Digester TSS* | 9550 | 10330 | 11300 | 11130 | - |

* with the screen and HC in service (frQ_to_Sc_HC = 2%)

Finally, other aspects of the performance of the scenario 2 were studied. In average, the oxygen uptake rate (OUR) in the aeration basin was estimated to 40 mg/L.h, including 30 mg/L.h due to the nitrification. The COD and nitrogen concentrations levels in the treated effluent testify for good performance of the nitrification (> 25 mg/L L N-NO₃ produced) and of the organic matter removal. The ammonia nitrogen (S_{NH}) and the biodegradable organic matter (S_s) were reduced to less than 2 mg/L.

4. CONCLUSIONS

The modified ASM1 model, including a slow degradation process of the endogenous residues X_P in a digester, combined with black-boxes representing the physical removal of the inerts (X_I and ISS), adequately reproduced the apparent behavior of activated sludge with low sludge production (LSP-AS).

According to the simulations performed, a conventional activated sludge process (C-AS) may be substituted by an LSP-AS process (sieve, HC and on-line RAS-digester) that would operate with similar levels of active biomass and MLTSS in the aeration basin.

For the studied wastewater influent and for a k_{XP} value of about 0.007 d⁻¹, at least 2% (and 6%) of the RAS flow must be sieved (and digested, respectively), to avoid the accumulation of X_I, ISS and X_P. Also, the size of the on-line digester will be about twice the volume of the aeration tank.

The mathematical model implemented in Aquasim could serve as didactical, operational and research simulation tool for LSP-AS processes.

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REFERENCES

- Fall C. and Loaiza-Navia J. (2007). Design of a Tracer Test Experience and Dynamic Calibration of the Hydraulic Model for a Full-scale WWTP by Use of AQUASIM. *Water Environ. Res.*, 79 (8), 893-900.
- Henze M., Gujer W., Mino T. and Van Loosdrecht M.V. (2000) Activated sludge models ASM1, ASM2, ASM2d and ASM3, IWA Publishing, London, 130 p.
- Johnson B.R., Daigger G.T. and Novak J.T. (2008). The Use of ASM based Models for the Simulation of Biological Sludge Reduction Processes. *Water Practice & Technol.*, 3 (3), IWA Publishing, 10p.
- Jones R., Parker W., Khan Z., Murphy S. and Rupke M. (2007). A study of the biodegradable fraction of Sludge in aerobic and anaerobic systems. *Residuals and Biosolids Management*, WEF Conference, Proceedings, p- 20-35.
- Low E.W. and Chase H.A. (1999). Reducing production of excess biomass during wastewater treatment. *Water Res.*, 33(4), 1119-1132.
- Mansour-Geoffrion M., Dold P.L., Lamarre D., Gadbois A., Deleris S. and Comeau Y. (2010). Characterizing Hydrocyclone Performance for Grit Removal From Wastewater Treatment Activated Sludge Plants. *Minerals Engineering*, 23(4), 359-364.
- Novak J.T., Chon D.H., Curtis B.A. and Doyle M. (2007). Biological Solids Reduction Using the Cannibal Process. *Water Environ. Res.*, 79 (12), 2380-2386.
- Ramdani A., Dold P., Gadbois A., Délérís S., Houweling, D. and Comeau Y. (2012). Biodegradation of the endogenous residue of activated sludge in a membrane bioreactor with continuous or on-off aeration. *Water Res.* 46 (9), 2837-2850.
- Reichert P., (1998). AQUASIM 2.0. User Manual. Swiss Federal Institute for Environmental Science and Technology (EAWAG), Switzerland. 219 p.
- Ruiken C.J., Klaversma E. and van Loosdrecht M.C.M. (2011). Removal of toilet paper from influent of municipal wastewater treatment by sieves. *Proceedings, 11th IWA Specialized Conference on*

- Design, Operation and Economics of Large WWTP, 4–8 Sept. 2011, Budapest, Hungary. P. 191-198.
- Sperandio M., Labelle M.A., Ramdani A., Gadbois A., Paul E., Comeau Y. and Dold P. (2013). Modelling the degradation of endogenous residue and “unbiodegradable” influent organic suspended solids to predict sludge production. *Water Sci. Technol.*, 67 (4), 789-796.
- Troiani, C., A.L. Eusebi and P. Battistoni (2011). Excess sludge reduction by biological way: From experimental experience to a real full-scale application, *Bioresource Technol.*, 102 (22), 10352-58.