USING NUMERICAL SIMULATION SOFTWARE FOR IMPROVING WASTEWATER TREATMENT EFFICIENCY

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Abstract:

The aim of this paper is to show the using of numerical software in order to improve the wastewater treatment plants efficiency from the design phase. The use of computer simulation programs to evaluate and design wastewater treatment plants is becoming more prevalent; design engineers often implement models without adequate influent characterization and calibration. In this paper the STOAT (Sewage Treatment Operation and Analysis over Time) software is considered to simulate a real wastewater treatment plant, to analyze the solids retention time and the nutrients (N and P compounds) in the effluent taking into account different activated sludge models.

Keywords: wastewater treatment, effluent, nutrients, STOAT

Introduction

The simulation programs are used more frequently in order to evaluate and design the wastewater treatment plants. Simulation software's for activated sludge modeling are used for a range of purposes, including option screening, process sizing, detailed design, plant optimization and process control. Because of limited data, time and budget, these simulation programs are often used without adequate influent wastewater characterization (definition of influent chemical oxygen demand and nitrogen fractions) and/or model calibration (adjusting kinetic and stoichiometric parameters within the model to achieve the same effluent quality of the actual plant).

The activated sludge settling tanks models in STOAT are based on the works of Takacs [1].

There are five settling models available and they should be used depending on which aeration tank model is being used as follows:

Table 1 STOAT available settling models

Aeration model	ASAL 1 (1A)	ASAL 2 (2A)	ASAL 3 (3A)	ASAL 5 (5A)	IAWQ#1	IAWQ#2
Settling model	SSED 1	SSED 2	Generic	SSED 5	Generic	Generic

In the present paper the ASAL1, ASAL5 and ASM2d (full N) and the phosphorous chemical removal tank are analyzed. In the aeration tanks are used one or two mixed liquor suspended solids (MLSS) recycling in order to improve the nitrogen removal.

Methodology

The STOAT model comprises a number of differential equations written as mass balance for completely mixed reactor. Increasing the number of reactors in series increases the model's approach to plug flow. In figure 1 is shown the simulation flowchart composed from: influent, grit chamber, two primary sedimentation tanks, 4 activated sludge aeration tanks, two secondary sedimentation tanks and the effluent discharge.

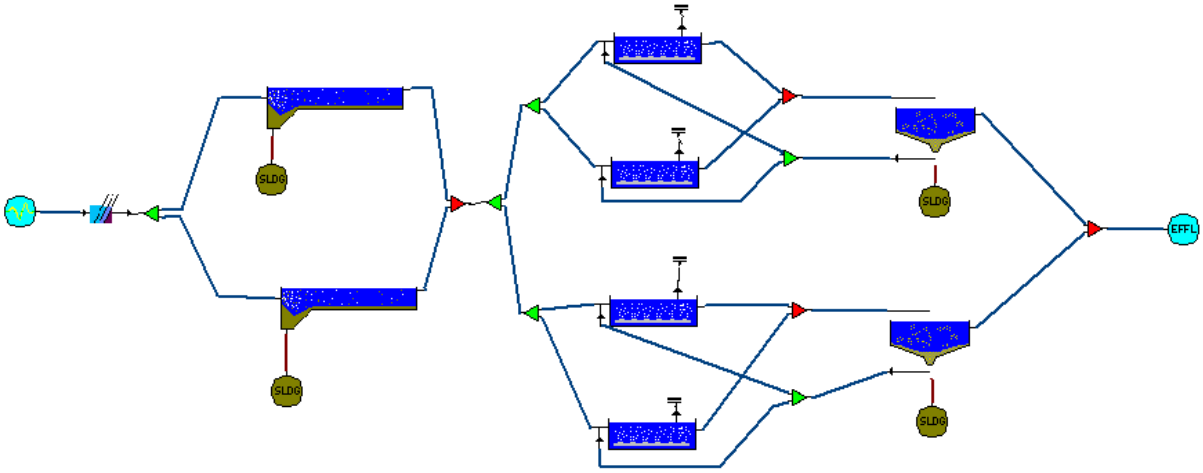


Figure 1. STOAT simulation flowchart

The components for each tank are listed below. Autotrophs are ammonia users and heterotrophs BOD users.

Table 2 Influent wastewater components

Component	**Name**	**UM**
S_{NH3}	Ammonia	[mg/l]
S_{NO3}	Nitrate	[mg/l]
S_{O}	Dissolved oxygen	[mg/l]
S_{P}	Soluble phosphate	[mg/l]
S_{S}	Soluble BOD	[mg/l]
$X_{A,V}$	Viable autotrophs	[mg/l]
$X_{A,NV}$	Nonviable autotrophs	[mg/l]
$X_{H,V}$	Viable heterotrophs	[mg/l]
$X_{H,NV}$	Nonviable heterotrophs	[mg/l]
X_{T}	Mixed liquor suspended solids	[mg/l]

The model ASAL 1 recognizes that utilization of substrate can occur without consumption being coupled to growth.

The equation that describes the BOD removal is:

$$\frac{dS_S}{dt} = Q(S_{S,in} - S) - \frac{\mu_H}{Y_H} X_{H,V} V - \psi X_{H,NV} V \tag{1}$$

The inlet term $Q\ S_{s,in}$ includes the effects of sewage, return activated sludge, mixed liquor recycles and the normal flow of mixed liquor through the activated sludge tank.

The equations for viable, respectively nonviable heterotrophs can be written:

$$\frac{dX_{H,V}}{dt} = Q(X_{H,V,in} - X_{H,V}) + \mu_H X_{H,V} V \tag{2}$$

$$\frac{dX_{H,NV}}{dt} = Q(X_{H,NV,in} - X_{H,NV}) - K_D X_{H,NV} V \tag{3}$$

The same equations are repeated for autotrophs with ammonia and autotrophic bacteria replacing BOD and heterotrophic bacteria. The uptake of oxygen uses the following equation, allowing oxygen uptake by both BOD and ammonia oxidation and the transfer of oxygen into the sewage through aeration:

$$\frac{dS_O}{dt} = \frac{Q}{V}(S_{O,in} - S_O) + K_L a(S_O^* - S_O) - \frac{\mu_H}{Y_H} X_{H,V} - \psi_H X_{H,NV} - Y_{O,NH_3}\left(\frac{\mu_A}{Y_A} X_{A,V} - \psi_A X_{A,NV}\right) - -M_{O_2} \frac{S_O}{K_O + S_O} X_T \tag{4}$$

The growth and enzyme terms use similar equation forms:

- Monod term for growth kinetics:

$$\mu = \frac{\mu_{\max S}}{K_S + S} \frac{S_O}{K_O + S_O} \tag{5}$$

- Michaelis - Menten term for enzyme kinetics:

$$\psi = \frac{\psi_{\max S}}{K_S + S} \frac{S_O}{K_O + S_O} \tag{6}$$

The model allows the use of nitrate as an oxidizing agent when this would favor bacterial growth. Only heterotrophic bacteria are capable of utilizing nitrate. The decision as to which to use is made by calculating the growth rate on oxygen and nitrate and selecting whichever is the larger of the two. An essential part of the model is the transition from viable to nonviable cells. Heterotrophic bacteria isolated from sewage treatment plants have been found to have maximum specific growth rates of about 0.3 h^{-1} at 15-20°C. This compares with specific growth rates of 0.008 h^{-1} or less for typical activated sludge plants. At such low proportions of their maximum specific growth rate bacterial cultures are known to lose viability, and the probability of cell division resulting in the production of nonviable cells increases [2].

Activated sludge model 5 is the same as model 1 but includes a simple model of biological P-removal. The equation for P-uptake is:

- removal of soluble phosphorus through biological uptake:

$$\frac{dS_P}{dt} = \frac{Q}{V}(S_{P,in} - S_P) - \mu_H X_{H,V} P_X \tag{7}$$

- increase in phosphorus stored in biomass:

$$\frac{dX_P}{dt} = \frac{Q}{V}(X_{P,in} - X_P) + \mu_H X_{H,V} P_X \tag{8}$$

One additional variable to the ten in model 1 is required. This is X_P, the concentration of phosphorus within the sludge biomass.

P_X is the phosphorus content of the heterotrophic bacteria, typically in the range 1-5%. Phosphorus uptake is only permitted if at least one zone within the aeration tank is anaerobic, taken to be dissolved oxygen less than 0.1 mg/l and nitrate less than 0.5 mg/l.

Simulation results

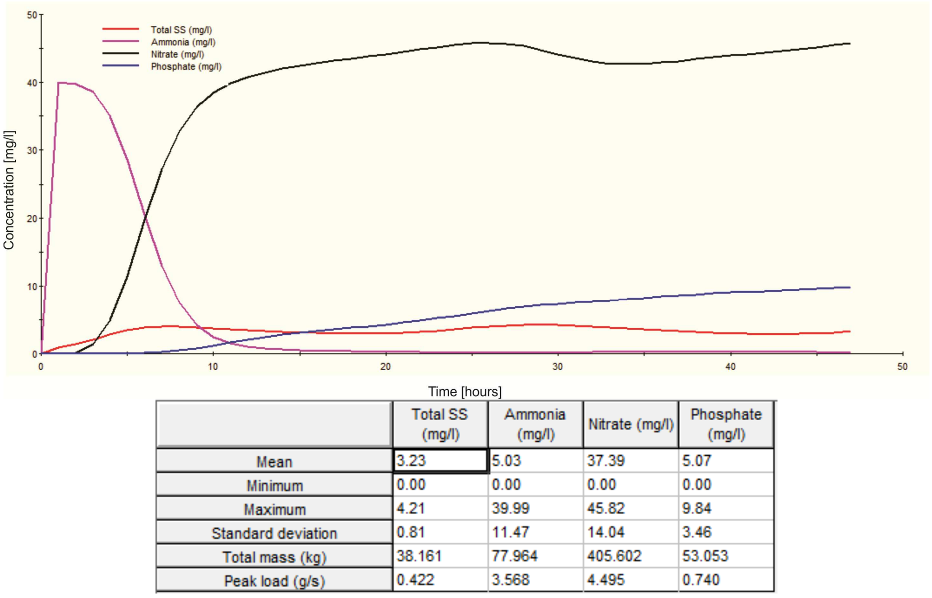
The following influent characteristics are considered for the simulation:

- wastewater flowrate = 375m^3/h
- pH = 7
- volatile fatty acids = 7,5mgCOD/l
- soluble biodegradable COD = 225 mg/l
- volatile solids = 270mg/l
- nonvolatile solids = 90 mg/l
- ammonia = 60 mg/l
- soluble phosphate = 15 mg/l

The results of the numerical simulation will be compared with the parameters limits for wastewater discharge in natural streams according to Romanian legislation (NTPA 001); such as ammonia 15mg/l, nitrate 25 … 37mg/l and phosphorus 1 … 2mg/l.

1st Case

It is considered one aerated stage in the activated sludge aeration tanks; the results are shown in figure 2.



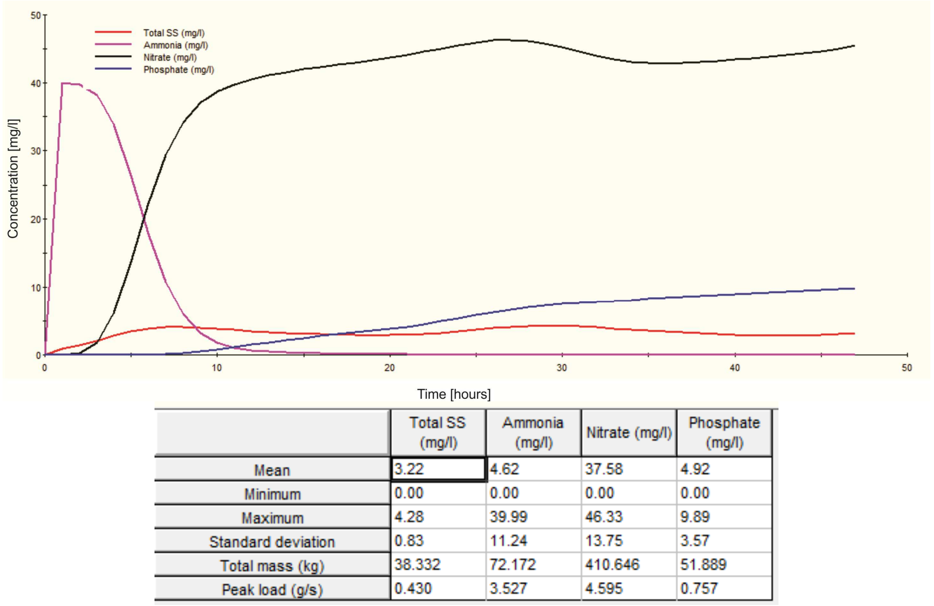
	Total SS (mg/l)	Ammonia (mg/l)	Nitrate (mg/l)	Phosphate (mg/l)
Mean	3.23	5.03	37.39	5.07
Minimum	0.00	0.00	0.00	0.00
Maximum	4.21	39.99	45.82	9.84
Standard deviation	0.81	11.47	14.04	3.46
Total mass (kg)	38.161	77.964	405.602	53.053
Peak load (g/s)	0.422	3.568	4.495	0.740

Figure 2. Parameters evolution for the 1st simulation case

It can be observed that by using only one stage in the aerated tanks it is enough for the nutrients removal, in order to reach the effluent discharge regulation.

2nd Case

It is considered one aerated stage and one anoxic stage in the activated sludge aeration tanks, with internal MLSS recycling; the results are shown in figure 3.



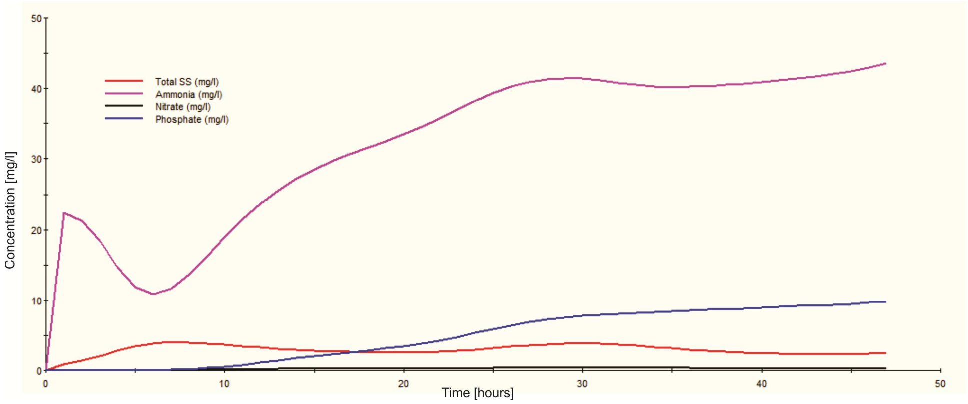
	Total SS (mg/l)	Ammonia (mg/l)	Nitrate (mg/l)	Phosphate (mg/l)
Mean	3.22	4.62	37.58	4.92
Minimum	0.00	0.00	0.00	0.00
Maximum	4.28	39.99	46.33	9.89
Standard deviation	0.83	11.24	13.75	3.57
Total mass (kg)	38.332	72.172	410.646	51.889
Peak load (g/s)	0.430	3.527	4.595	0.757

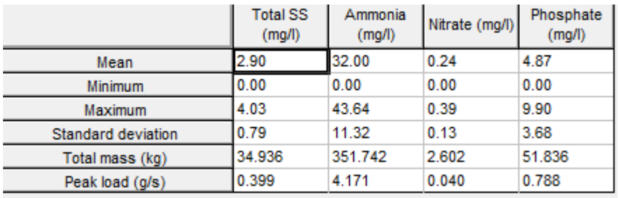
Figure 3. Parameters evolution for the 2nd simulation case

In the 2nd case it can be observed a reduction of phosphate concentration in the effluent. The nitrate concentration remains the same as in the first case. For this reason in the 3rd simulation case it is considered the ASM2 model.

3rd Case

It is considered one aerated stage and one anoxic stage in the activated sludge aeration tanks, with internal MLSS recycling; the results are shown in figure 4.





	Total SS (mg/l)	Ammonia (mg/l)	Nitrate (mg/l)	Phosphate (mg/l)
Mean	2.90	32.00	0.24	4.87
Minimum	0.00	0.00	0.00	0.00
Maximum	4.03	43.64	0.39	9.90
Standard deviation	0.79	11.32	0.13	3.68
Total mass (kg)	34.936	351.742	2.602	51.836
Peak load (g/s)	0.399	4.171	0.040	0.788

Figure 4. Parameters evolution for the 3rd simulation case

It can be observed a significant reduction of the nitrate in the effluent, but the phosphate concentration is out of regulations limits.

4th Case

In this simulation case it is introduced in the treatment flowchart a tank for chemical phosphorus removal as shown in figure 5. The phosphate precipitation is realized with iron (III) chloride ($FeCl_3$). The metal concentration is 40mg/l and for the first simulated case it is considered 1m^3/h flowrate. In activated sludge aeration tanks there are considered one aerated stage and one anoxic stage, with internal MLSS recycling. The simulation results are shown in figure 6.

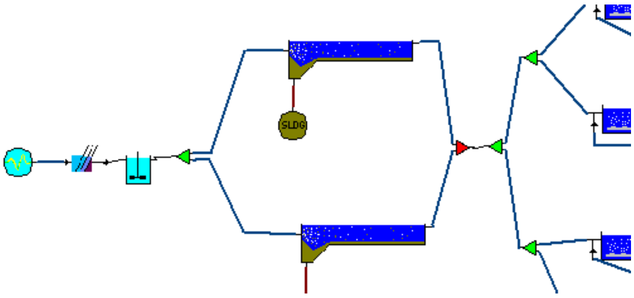
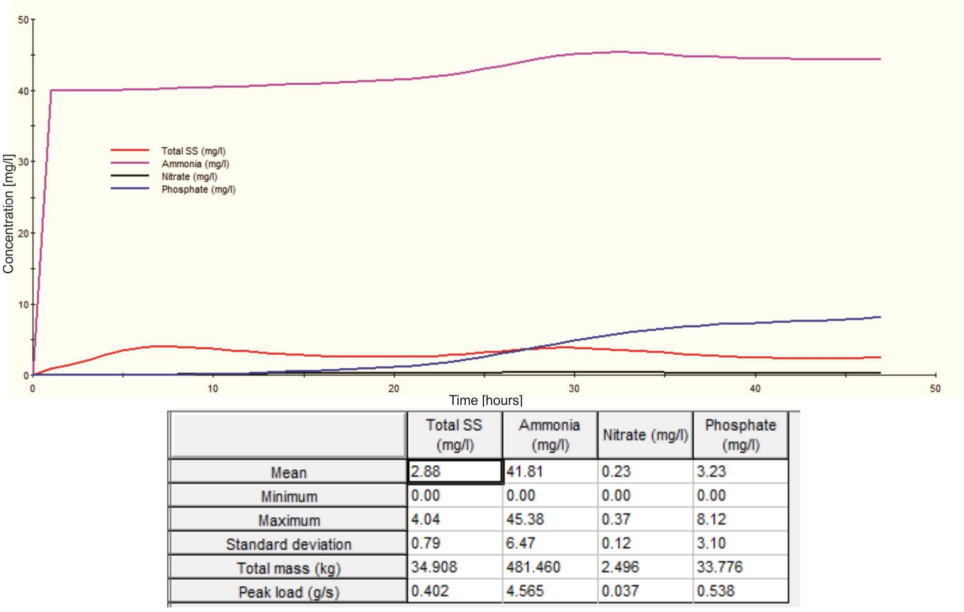


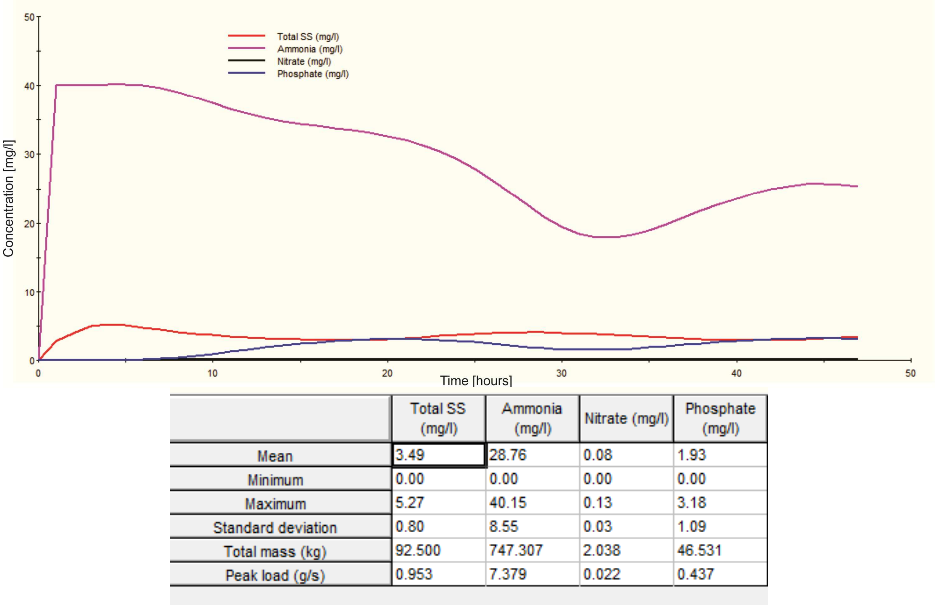
Figure 5. Introduction of the chemical phosphorus removal tank



	Total SS (mg/l)	Ammonia (mg/l)	Nitrate (mg/l)	Phosphate (mg/l)
Mean	2.88	41.81	0.23	3.23
Minimum	0.00	0.00	0.00	0.00
Maximum	4.04	45.38	0.37	8.12
Standard deviation	0.79	6.47	0.12	3.10
Total mass (kg)	34.908	481.460	2.496	33.776
Peak load (g/s)	0.402	4.565	0.037	0.538

Figure 6. Parameters evolution for the 4th simulation case

It can be observed a reduction of the phosphate concentration, but not significant. Further on the simulation there were made step by step simulations by increasing the $FeCl_3$ quantity introduced in order to reach a 2mg/l phosphate concentration in the effluent. After the model was run for each step, the desired phosphate concentration has been reached when 100m^3/h $FeCl_3$ flow rate is introduced. In figure 7 are shown the simulation results.



	Total SS (mg/l)	Ammonia (mg/l)	Nitrate (mg/l)	Phosphate (mg/l)
Mean	3.49	28.76	0.08	1.93
Minimum	0.00	0.00	0.00	0.00
Maximum	5.27	40.15	0.13	3.18
Standard deviation	0.80	8.55	0.03	1.09
Total mass (kg)	92.500	747.307	2.038	46.531
Peak load (g/s)	0.953	7.379	0.022	0.437

Figure 7. Parameters evolution when 100m^3/h $FeCl_3$ flow rate is introduced in the chemical phosphorus removal tank

In order to verify the model the requested $FeCl_3$ quantity has been stoichiometric calculated by taken into consideration the initial phosphate concentration. It has been considered a 0.2 phosphate efficiency removal in the primary settling tank, so that the phosphate concentration in the aeration tank is 13,19mg/l and the phosphate concentration after the biological treatment is considered 2 mg/l. The necessary 40% $FeCl_3$ quantity for phosphorus removal is 5900kg/day, which means 4.75 m^3/day. Taking in consideration the above can be notice a large discrepancy between the model and mathematical calculus of the necessary $FeCl_3$ quantity.

Conclusions

In this paper different models and numerical simulations were realized in STOAT software in order to show the using of the numerical programs to design and calibrate the wastewater treatment plant parameters. A complete analysis of the biological wastewater treatment process behavior under various activated sludge models was done. It is obtained the variation curves of the biomass, substrate and nutrients concentrations, for the ammonia and nitrates reduction the effluent values are in the limits of Romanian legislation, but in the case of phosphorous removal results very large amount for the ferric solution. Simulation studies should be carefully used and always should verify the results with experimental data. Due to the great differences between the results of the simulation model and the stoichiometric calculus for the $FeCl_3$ quantity necessary for phosphorous removal, further numerical simulation will be realized in order to determine the optimum model.

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