Modelling the active sludge treatment process in recirculation basins using the simulink environment

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Abstract: In the global context of environmental protection and the reduction of its pollution, wastewater treatment has a special role. Starting from this general framework and considering the need for an integrated approach to water as a natural resource, the aim is to introduce new treatment technologies in which human intervention tends to zero. That is why modelling, and simulation techniques highlight automation solutions and their implementation. In our paper we tried to model a biological purification process using Simulink techniques.

1. General Consideration

The main objective of the biological treatment step is the removal of non-sedimentable organic solids (dissolved or colloidal), as well as the stabilization of organic matter from sludge. At the same time, it is proposed to reduce nutrients based on nitrogen and phosphorus. It is a flexible process that can easily adapt to a multitude of wastewater, concentrations, and compositions. The biological processes are preceded by the physical treatment step which has the role of retaining the sedimentable substances and are followed by a secondary decantation -physical processes- intended to retain the products resulting from the biological treatment. The factors that influence the biological process are: the contact time or the time of crossing the technological objective with wastewater (dilution), with mud, nutrients, the presence of process inhibitors, the hydrodynamic conditions of the process - homogenization and mixing. The biological treatment process is particularly complex, and a series of phenomena are involved in solving it:

1. physical - mass transfer of oxygen and substrate to the cells, oxygen from air to water, adsorption of colloidal particles and fine suspensions at the surface of biomass, desorption of metabolic products, gravitational sedimentation, etc.;
2. chemical - hydrolysis, hydration, redox, precipitation and coagulation reactions, pH change;
3. biochemical - biochemical oxidation reactions of the substrate, endogenous respiration, biomass increase, inhibition of enzymatic reactions;
4. hydraulic - flow regime, distribution of polyphasic medium in the aeration basin, convection and density currents, hydraulic retention time, sedimentation speeds, hydraulic loads, etc.

The development of the biological process is dependent on maintaining constant parameters at the entry of wastewater into the treatment plant. The appearance of temporary shocks leads to the reduction
of the sludge sedimentation parameters, the disintegration of the activated sludge, the increase of the concentration of the solid suspensions in the effluent and finally to the blocking of the process.

2. **Modeling of the sludge treatment process in tanks with recirculation blocking process.**

The basic assumptions of modelling are formulated as follows:

- a) the hydraulic regime is permanent;
- b) the regime is chemically and biochemically stationary;
- c) the mixing of the participating phases is complete (active water-air-sludge);
- d) the biological degradation of organic matter is carried out entirely in the aeration basin.

In these hypotheses it is formulated by balance equations, the system describing the operation of the installation in dynamic mode.

![Figure 1](image.png)

**Figure 1** Calculation scheme for modelling

For the proper functioning of the biological step, the range of variation of the parameters is required:
\[ \alpha < 1; \beta = 0.25 - 0.40; S = 600 - 4000 \text{ mg/l} \]

\[ Q_e = \beta Q_n \]

Adjustment elements of the automation system will be \( Q_e \) and \( Q_{aer} \). These terms must appear in the equations of the biological process.

Base element \( C = 1 - 3 \text{ mgO}_2/\text{l} \) the concentration of residual oxygen in the biologically active aqueous environment.

Hydraulic balance - expresses the equations of continuity:
\[ Q_i + Q_R = Q_T = Q_E + Q_n \]

Equation of organic loading \( L \) - established by the mass balance method:

\[ m_{influential} + m_{recirculation} = m_{effluent} + m_{sludge} + m_{decomposed by biochemical reactions} \]

\[ Q_i * L_i + Q_R * L = Q_E * L_E + Q_n * L + (dL / dt * V)^{-1} \]
Decomposition speed \( \frac{dL}{dt} = K_{LS} \) plus other terms that depend on \( L \), \( S \), oxygen, mixing, etc. The equation of loading into active sludge shall also be established on the basis of the mass balance in the form of:

\[
m_i^{\text{influent}} + m_i^{\text{recirculation}} = m_e^{\text{effluent}} + m_e^{\text{sludge}} + \text{biomass growth through biochemical synthesis} - m_{\text{activate endogenous consumption}}
\]

\[
Q_i \cdot S_i + Q_n \cdot S_d = \left( dS \cdot dt \cdot V_{\text{growth}} \right)^{-1} - \left( VdS \cdot dt_{\text{consumer}} \right)^{-1} + Q_e \cdot S_e + Q_n \cdot S
\]

Biomass growth depends on \( L \), \( S \), oxygen, mixing, nutrients (N, P).

Oxygen balance equation:

\[
O_{i\text{Influent}} + O_{i\text{Recirculation}} + O_{\text{Supplied equipment}} = O_{\text{Biochemical consumption}} + O_{\text{Endogenous breathing consumption}} + O_{\text{Required mixing}} + O_{\text{Effluent}} + O_{\text{Sludge}}
\]

\[
Q_i \cdot C_i + Q_R \cdot C_R + \left( \frac{dC}{dt} \right)_{\text{Transfer from air}} = \left( \frac{dC}{dt} \right)_{\text{Biological consumption}} \cdot V_{\text{Organic loading volume}} + \left( \frac{dC}{dt} \right)_{\text{Endogenous consumption}} \cdot V_{\text{Active sludge volume}} + \rho \cdot G \cdot V + C \cdot Q_e + C \cdot Q_n
\]

where \( C \) is the concentration of oxygen in the water mass.

Therefore, there are 4 equations characteristic of the biological purification process with active sludge:

A) \( Q_i + Q_R = Q_e + Q_n \)

B) \( Q_i \cdot L_i + Q_n \cdot L = Q_i \cdot L + Q_n \cdot L + (dL/dt)_{\text{Consumer}} \)

C) \( Q_i \cdot S_i + Q_n \cdot S_d = (dS/dt)_{\text{1 Biomass growth}} \cdot V - (dS/dt)_{\text{2 Endogenous consumption}} \cdot V + Q_e \cdot S_e + Q_n \cdot S \)

D) \( Q_i \cdot C_i + Q_R \cdot C_R + (dC/dt)_{\text{Transfer from air}} \cdot V = (dC/dt)_{\text{Biochemical consumption}} \cdot V_{\text{Organic loading volume}} + (dC/dt)_{\text{Endogenous consumption}} \cdot V_{\text{Active sludge volume}} + \rho_{\text{Water}} \cdot GV + C_e \cdot Q_e + CQ_n \)

In this model, the correlations between sizes appear, but the terms necessary for the adjustment process do not explicitly stand out. Although these systems of equations are correct and original in the given form are difficult to apply and interpret in the automation process. For the automation of the biological treatment plant it is easier to highlight the elements on which the adjustment will be intervened - the flow of instilled air and the flow of recirculated sludge.

3. Simulink Modelling

The conventional process with active sludge shown in figure 2 shall be considered:
The equation system was used to simulate the evolution of biomass concentration, substrate concentration (organic loading) and dissolved oxygen concentration over time using the Matlab-Simulink program, a specific program for modelling, analysing and simulating dynamic systems.

\[
\begin{align*}
\frac{dS_1}{dt} &= \frac{Q + Q_4}{V}(\frac{Q_4}{Q_3} - 1)S_1 + \frac{\mu_n}{K_S + L_1}L_1S_1 - K_dS_1 \\
\frac{dL_1}{dt} &= \frac{Q}{V}L_1 - \frac{\mu_n}{V}L_1S_1 \\
\frac{dO}{dt} &= 480144 \frac{Q_{ser}}{V} - \frac{a(Q + Q_4)}{V}(L_1 - L) - K_dS_1
\end{align*}
\]

The blocks in the data bank - the simulink standard library were used to make the model, the parameter values for each block being set to those corresponding to the equation system studied. The analysis of the model was carried out by simulating using the Simulink menu bar and visualizing the system's behaviour through "Scope" windows, marked "X_1", "L_1", and "O_1" in Figure 3, in which the time-based variation in biomass concentration, substrate concentration and oxygen concentration is observed. In the "X_1, L_1, O_1" window, you can compare directly, on the same chart, the evolution over time of the studied sizes.

From the methods of integration of the ordinary differential equations made available by the Simulink program, integration was chosen by the Runge method. Kutta of order 5 with initial conditions for substrate concentration \(L_{10} = 250 \text{ mg/l}\), concentration of microorganisms \(X_{10} = 500 \text{ mg/l}\) and concentration of dissolved oxygen in the aeration basin \(O_{10} = 5 \text{ mg/l}\). The influential wastewater flow is \(Q_{in} = 20 \text{ m}^3/\text{s}\), and the volume of the aeration basin \(V = 270000 \text{ m}^3\).
Figure 3. Simulink model for the study of the over-behaviour of biomass, substrate and dissolved oxygen concentrations over time

4. Results

As a result of the implementation of the model, the results expressed in the form of graphs are obtained, namely:

Figure 4. Variation in biomass concentration in the aeration basin over time.

The concentration is increased to 1.5 times as a result of abundant food in the aeration basin and then a decrease in the effect of decreasing the BOD.
There is a rapid decrease in BOD correlated with biomass growth up to 1.5 times.

The diagram shows that the retention time in the aeration basin must be less than 6 hours.

Variation over time in biomass concentration, substrate concentration and dissolved oxygen concentration.
Figures 4, 5, 6, 7 show a variation in the sizes studied in full accordance with reality. Organic loading decreases to 20 mg/l in approximately 2.5 hours. If retention time is increased in the aeration basin, the amount of biomass is insufficient to reduce the concentration of the substrate and also the concentration of dissolved oxygen decreases. The variation of the three curves correlates well in the range of variation of up to 2.5 - 3.0 hours while the wastewater should be in the biological reactor. At the same time, these variance curves, obtained with the help of the Simulink program, correlate with the others obtained in Matlab and with the evolution model of the unitary biological process.

5. Conclusion

The Simulink model allows the trace of the variance curves of organic load, biomass and oxygen requirements. All these curves correlate perfectly and are adaptable to the real process of mineralization of organic materials in the aeration basin. Thus, a conclusion resulting from the practice can theoretically be justified, namely: in the aeration basin the retention time is less than 6 hours. The conclusion is self-evident. The retention time of wastewater in the aeration basin must be between 3 - 4 hours (0.25 days is maximum). Otherwise, at retention times of 6 hours and more, the oxygen requirement has decreased greatly, as a result of the decrease of organic loading, and so an aeration (an unjustified energy consumption) of the watery environment is made.

6. References

[1]. Batten G L Jr., Programmable contolers - Hardware, Software & Applications, McGraw - Hill, 1994.
[2]. Cox E, Fuzzy logic for business and industry. Charles River Media, Rockland, Mass., 1995.
[3]. Mannesmann Demag AG Eeequipment of the Bucharest municipality wastewater treatment plant, 1997.
[4]. Metcalf I and Eddy C, Wastewater engineering. Treatment, disposal and reuse. Mc.Graw Hill, 1991.
[5]. Robescu D N and Meiroșu G, A managerial approach of the power cost control into the wastewater treatment plants, The VIII-th Symposium “Technologies, plants and equipment for improvement of environmental quality” 1999.