MODELING OF ATTACHED GROWTH BIOLOGICAL WASTEWATER TREATMENT PROCESSES

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The paper presents a theoretical model for kinetics of mobile bed biological wastewater treatment processes. Global mass balance equations are used for predicting substrate removal and microorganism growth in biological reactor. An original expression for active mass of microorganism in biofilm was introduced. A simulation study was conducted for predicting substrate removal and microorganism growth in the system, using a Simulink model.

Keywords: wastewater treatment, attached growth biological treatment, modeling, simulation

1. Introduction

Biological wastewater process is a particularly complex process to which contribute phenomena of different nature, such as physical, chemical, biochemical. The Norwegian University of Science and Technology and Kaldnes Miljoteknologi A/S of Norway developed the mobile bed biofilm reactor system (MBBR). This system consists of a reactor vessel containing mixed liquor suspended solids with specially designed small floating carrier media suspended and kept in constant circulation. A screen is provided at the outfall end of the reactor to keep media from clogging the effluent spout or passing out of the reactor. The media is engineered in a wheel shape and is slightly positively buoyant, allowing a small amount of water flow (created by adding air to the process) to circulate the media throughout the vessel. Oxygen and food (ammonia and nitrite) gives the bacteria the means to grow, whilst the Kaldnes media provides maximum surface area for the bacteria to colonize and produce biofilm. This is a very modern technology, but it is not implemented in our country.

In the present there are some theoretical researches concerning modeling and simulation of wastewater treatment with moving bed biofilm. The studies have more practical character, for implementing this new technology in different wastewater treatment plant and for study efficiency for different types of

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pollutants: Odegaard et. al. [1-3], Andreottola et. al. [4], Rodgers and Zhan [5]. Several biofilms models have been published over the past 20 years. Mostly of them refers to clasic biofilm technology. These vary in complexity from simple analytical model to full 3-D dynamic models. In Diana Robescu et.al. [6] there are presented some biofilm models at micro-scale level. An extensive summary is provided by Wanner et al. [7].

This paper presents a model developed based on mass balance equation and taking into account the mass of biofilm in the tank.

2. Mathematical modeling

Consider the schematic representation of MBBR without recycle and a control volume V with enter point 0 and outlet point 1 (see fig. 1).

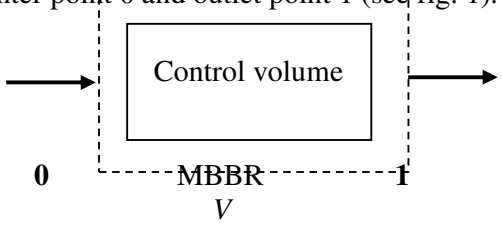

Fig.1. Scheme of MBBR processes.

Conservation of mass of a component in a dynamic and open system states that: net rate of accumulation of mass component in the system = mass flow of the component into the system – mass flow of the component out of the system + rate of production of the component by transformations – rate of consumption of the component by transformations [7].

In non-steady-state conditions, taking into account complete mixing in bioreactor and neglecting endogenous decay of microorganism, equation for mass balance of microorganism in control volume, for the whole biofilm system, can be written as:

$$\frac{d(X_1 V)}{dt} = Q_0 X_0 - Q_1 X_1 + \mu(t)_b M_b + \mu(t)_l X_{1l} V \qquad (1)$$

where X – microorganism concentration (subscript 0 or 1 are for the two points of control volume); V – biological reactor volume; Q – wastewater flowrate; $\mu(t)_b$ – net growth rate of microorganism in biofilm, $\mu(t)_l$ – net growth rate of microorganisms in suspension; M_b – active mass of microorganism in biofilm.

The substrate balance is determined by the equation:

$$\frac{d(S_1V)}{dt} = Q_0S_0 - Q_1S_1 - \frac{\mu(t)_b}{Y_b}M_b - \frac{\mu(t)_l}{Y_l}X_{1l}V \quad (2)$$

where S – substrate concentration, Y_b – yield coefficient for biofilm, Y_l – yield coefficient for suspension.

Considering net growth of microorganism expressed by Monod equation for one limiting substrate, neglecting inhibition terms, $\mu(t) = \frac{\mu_m \cdot S}{K_s + S}$, where μ_m – maximum specific growth rate; K_s – saturation constant, named half-velocity constant and taking into account continuity, $Q_0 = Q_1$ and constant control volume, equations (1) and (2) become:

$$\frac{dX_1}{dt} = \theta \cdot (X_0 - X_1) + \frac{\mu_m \cdot S_1}{K_{sb} + S_1}\frac{M_b}{V} + \frac{\mu_m \cdot S_1}{K_{sl} + S_1}X_{1l} \quad (3)$$

$$\frac{dS_1}{dt} = \theta \cdot (S_0 - S_1) - \frac{\mu_m \cdot S_1}{K_{sb} + S_1}\frac{1}{Y_b}\frac{M_b}{V} - \frac{\mu_m \cdot S_1}{K_{sl} + S_1}\frac{1}{Y_l}X_{1l} \quad (4)$$

where $\theta = 1/t_r$, t_r – medium residence time.

The carrier element has a width of 7 mm and a diameter of 10 mm. It is reinforced in the inside with a cross, which provides harborage for microorganisms. The effective specific area of the medium is 500 m^2/m^3. The percent of reactor volume comprised of media is limited to 70%, with 67% being typical [1]. Adequate turbulence sloughs off excess biomass and maintains adequate thickness of biofilm. Biofilm thickness less than 100 μm for full substrate penetration is usually preferred, [8].

Active mass of microorganism is $M_b = X_b \cdot V_b$, where X_b – concentration of microorganism in biofim, V_b – biofilm volume. Considering a uniform repartition of biofilm over the entire surface of carrier elements, total biofilm volume can be calculated as $V_b = 0.67 \cdot V \cdot A_{spec} \cdot \delta$, where A_{spec} – specific area of carrier element and δ – thickness of biofilm. Thus, active mass of microorganism will be $M_b = X_b\, 0.67\, V\, A_{spec}\, \delta$ and inserting this expression into (3) and (4) result:

$$\frac{dX_1}{dt} = \theta \cdot (X_0 - X_1) + \frac{\mu_m \cdot S_1}{K_{sb} + S_1} \cdot X_b \cdot 0.67 \cdot A_{spec} \cdot \delta + \frac{\mu_m \cdot S_1}{K_{sl} + S_1}X_{1l} \quad (5)$$

$$\frac{dS_1}{dt} = \theta \cdot (S_0 - S_1) - \frac{\mu_m \cdot S_1}{K_{sb} + S_1}\frac{1}{Y_b}X_b \cdot 0.67 \cdot A_{spec} \cdot \delta - \frac{\mu_m \cdot S_1}{K_{sl} + S_1}\frac{1}{Y_l}X_{1l} \quad (6)$$

If one considers the same expression for net specific growth rate and the same concentration of microorganism both for biofilm and for suspension, equations (6) and (7) can be written as:

$$\frac{dX_1}{dt} = \theta \cdot (X_0 - X_1) + \frac{\mu_m \cdot S_1}{K_s + S_1} \cdot X_1 \cdot (0.67 \cdot A_{spec} \cdot \delta + 1) \quad (7)$$

$$\frac{dS_1}{dt} = \theta \cdot (S_0 - S_1) - \frac{\mu_m \cdot S_1}{K_s + S_1} \frac{1}{Y} \cdot X_1 \cdot (0.67 \cdot A_{spec} \cdot \delta + 1) \tag{8}$$

In order to generalize, the model is written using dimensionless terms, considering $X_1^*=YS_0$, $t^*=1/\theta$, $S_1^*=S_0$ and replacing $X_1=X_1^*X_1'$, $S_1=S_1^*S_1'$, $t=t^*t'$ [9]:

$$\frac{dX_1'}{dt'} = X_1' \left[\frac{\mu_m' S_1'}{K_s' + S_1'} (0.67 \cdot A_{spec} \cdot \delta + 1) - 1 \right] \tag{9}$$

$$\frac{dS_1'}{dt'} = 1 - S_1' - X_1' \frac{\mu_m' S_1'}{K_s' + S_1'} \cdot (0.67 \cdot A_{spec} \cdot \delta + 1) \tag{10}$$

where $\mu_m'=\mu_m/\theta$, $K_s'=K_s/S_0$.

3. Simulation study

Theoretical simulation study was conducted for predicting substrate removal and microorganism growth in the system. A Simulink model was made starting from equations (9) and (10), (fig.2).

Various scenarios were taken into account, considering different values for biofilm thickness and for dimensionless kinetic parameters μ_m' and K_s' (μ_m'= 0.1, 0.5, 1.0, 1,5, 2, 2.5, 3, 3.5, 5.0,10.0 and K_s'=0.05, 0.1, 0.2, 0.5, 1.0, 2.0, 2.5, 5.0, 10.0). Some of the results are presented in fig. 3 and fig. 4. For $\mu_m'=constant$, fig.4, one can observe influence of dimensionless constant K_s' on process dynamics. As it increases, microorganism concentration decreases and substrate concentration increases. This is due to its influence on net specific growth rate, independently with the substrate concentration. Value $K_s'=1$ is a special case when the constant is equal with influent substrate concentration. If K_s' is constant, fig.3, one can observe increasing of μ_m' as the substrate concentration decreases and microorganism concentration increases.

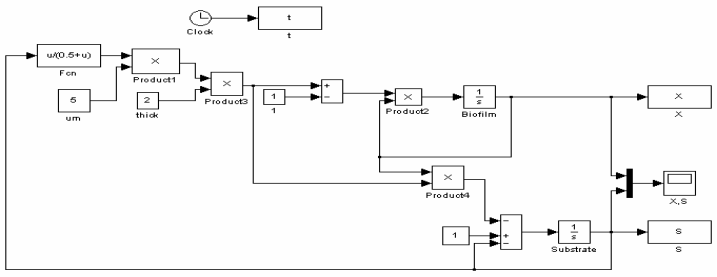

Fig. 2. Simulink model.

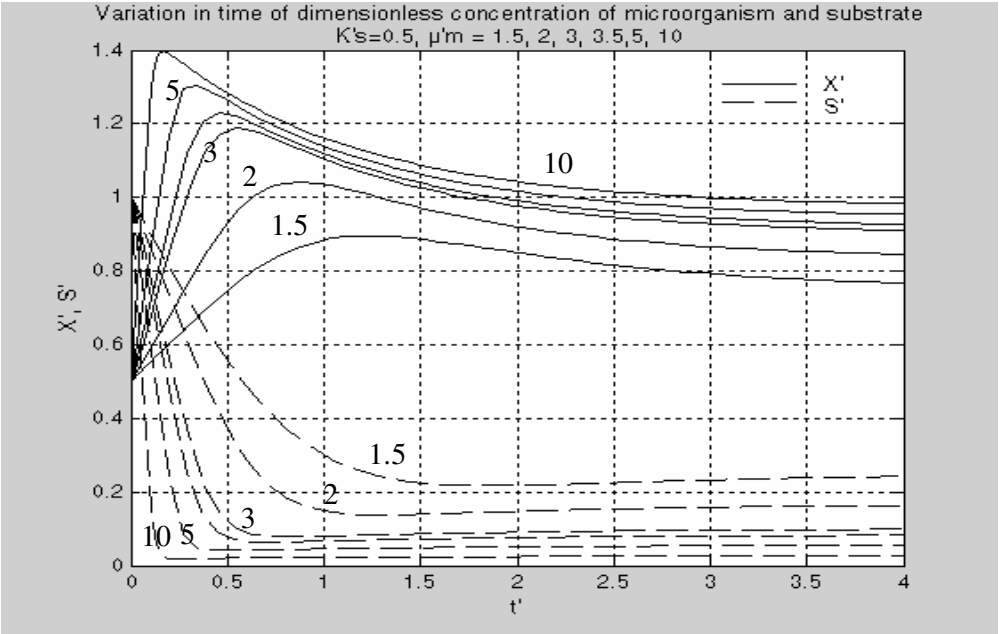

Fig. 3. Variation in time of dimensionless concentration of microorganism and substrate for K_s' =const and μ_m' variable.

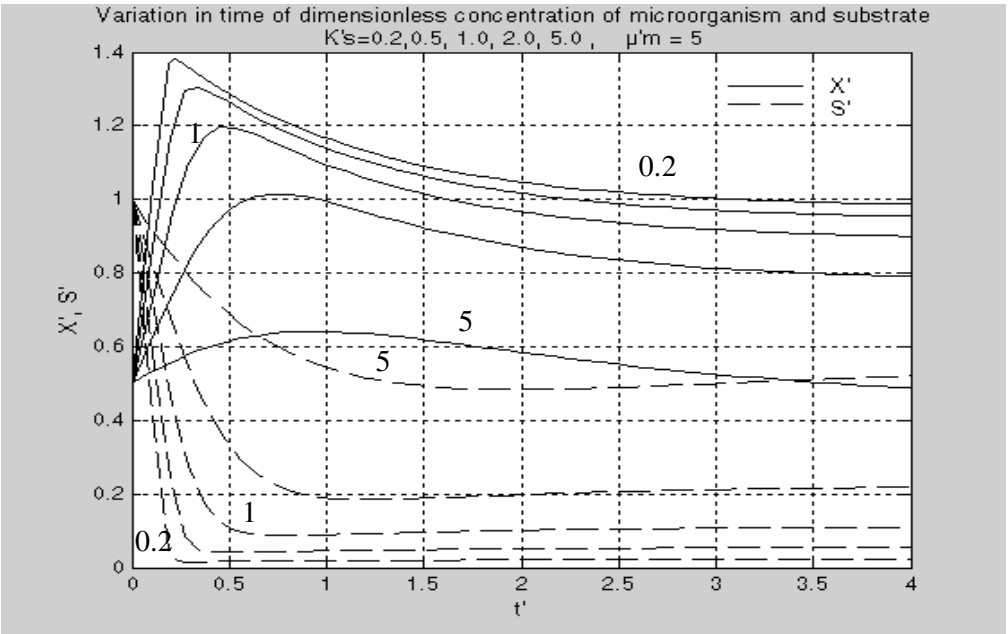

Fig. 4. Variation in time of dimensionless concentration of microorganism and substrate for μ_m' =const and K_s'variable.

4. Conclusions

The kinetic model for MBBR system was investigated. A mathematical model has been developed based on mass balance. An original expression for active mass microorganism in biofilm was introduced, taking into account specific area of carrier element, thickness of biofilm and the percent of reactor volume comprised of media. Theoretical results showed the influence of different parameters on the process dynamics. The theoretical model will be experimentally verified by using laboratory-scale mobile bed biofilm reactor made in Laboratory of Modeling and Simulation of Multiphase Flow and Wastewater Treatment Processes Laboratory of University "Politehnica" of Bucharest.

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