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(11) THE FUNCTIONAL ROLE OF THE BIOMASS TURN-OVER TIME IN BIOLOGICAL TREATMENT SYSTEMS

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ABSTRACT; Classical Monod model is often unadequate to the experimental data of the biological treatment processes. In some cases it is important to consider the poorly-decayed substrates or metabolic products. One of the surprising phenomenon from chemical engineering point of view is an effect of the influent pollutant concentration on the pollutant consumption rate. This phenomenon is explained in the paper by a heterogeneous nature of the pollutant and biomass. The corresponding mathematical models are discussed. These models show that a mean solids retention (biomass turn-over) time is a very important integral parameter of the biological treatment processes. Under the population shifts the consumption rate of the summary pollutant can be dependent on the influent pollutant concentration.
KEYWORDS;biological treatment,solids retention time,population shift,multicomponent pollutant,mathematical models

1.INTRODUCTION; In the course of biological treatment,the excess biomass is either forcibly removed as in activated sludge system or is released into the bulk liquid by passing luquid stream as in fixed-film reactor. The export of excess biomass determines the value of a mean solids retention (biomass turn-over) time. Mean solids retention time θ as well as specific total biomass growth rate $\mu = 1/\theta$ are very important integral parameters in the biological treatment systems. At small θ only fast-growing species will be preserved in the biological community.
The description of biological treatment process has been traditionally based on an equations deriving from chemical kinetics and classical microbiological dynamics. By using the new type models that take into account the heterogenity of a biomass and a substrate,new and subtler problems can be solved,leading eventually to greater understanding of mechanisms of biological processes.
The goal of this paper is not to quantitatively reproduce some known phenomena,but rather to give some insight into the mechanisms which cause them. Some multi-species/multi-component models of biological treatment were calibrated and tested earlier[15-16].

2.FORMAL BIOLOGICAL TREATMENT KINETICS; In the biological treatment systems the summary pollutant concentration L and the concentration of total biomass B are measured usually. Classical Monod model suggested for pure microorganism's culture is used often for the description of a biological treatment process

$$dL/dt = - \mu_m BL/(Y(K_L + L))$$
$$dB/dt = \mu_m BL/(K_L + L) - K_d B \qquad (1)$$

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where μ_m and K_d are the maximum specific growth rate and the decay rate of total biomass, K_L is the half-saturation coefficient, Y is the biomass yield coefficient.
Model (1) often is not adequate to the experimental data. To describe the kinetics of oxidation complex pollutant instead of Monod model a formal equation of an n-order can be used

$$dL / dt = - K_n B L^n \tag{2}$$

where K_n is the rate coefficient, n is a degree index;as a rule $n >= 1$.
A modified equation of the first order can be utilized also

$$dL / dt = - K_1 B(L - L_p) \tag{3}$$

introducing a correction L_p for poorly-oxidizes compounds. If summary pollutant concentration is measured in COD or TOC units this correction becomes more important. The value of L_p means the non-oxidizable substrates which are in the influent composition as well as the hardly-to-oxidizable metabolic products of microorganism's activity. Under the other conditions these compounds can be biologically assimilated[5].
Tucek et al.[14] demonstrated that in the course of a batch experiment the microorganism's activity depends on their previous state and what solids retention time was maintained at. Tischler and Eckenfelder[13] showed that the consumption rate of a number of simple substrate,including glucose,for the sludge taken from a system with a small biomass retention time θ was significantly higher as compared to the sludge taken from a system with a great value of θ.
For the continuously-flow biological treatment systems respective equations can be written in accordance with the type of the reactor (complete-mixing,plug-flow).For a complete-mixing reactor with biomass removal according to Monod model (1) the effluent steady-state concentration can be determined[11] from

$$B_e = \theta Y(L_o - L_e)/(T(1 + K_d\theta)) \tag{4}$$

$$L_e = 0 \text{ , if } \theta < \theta_{cr} \tag{5}$$

$$L_e = K_L(K_d + 1/\theta)/(\mu_m - (K_d + 1/\theta)) \text{ , if } \theta >= \theta_{cr} \tag{6}$$

where T is the waste water retention time and

$$\theta_{cr} = 1 / (\mu_m L_o/(K_L + L_o) - K_d) \tag{7}$$

where L_o is the influent pollutant concentration. So,if biomass retention time θ is rather small the slowly-growing microorganisms,for example nitrifiers,are displaced from the biomass.
Siber and Eckenfelder[12] investigated activated sludge system where a mixture of glucose,phenol and sulfanilic acid was employed as a substrate. An decrease of θ and change of the waste water composition were imitated by altering the proportion of the incoming substrates. They showed the necessity of inclusion of L_p value into the first order model. An analysis of the resulted data has shown that with decreasing θ the specific consumption rate of the labil substrate glucose elevetes faster than that of such more difficult-to-oxidize substrates as phenol and sulfanilic acid.

From some works it can be concluded that the consumption rate of summary pollutant depends not only on pollutant concentration in the reactor L_e but also on the influent pollutant concentration L_o[1,8,9,17]. This phenomenon is very surprising for chemical engineers. But in the biological treatment systems the biomass and the substrate are heterogeneous in nature and this is the main reason of such dependance.

According to Daigger and Grady[3] in the course of biological treatment process the hardly-to-oxidizable metabolic products appeared. If effluent pollutant concentration L_e is measured in COD the labil fraction of the organic compounds will be less than the value of L_e measured.

According to Vavilin[17] the generalized model of biological treatment process can be presented in the forms

$$dL/dt = -\mu_m BL^n/(Y(K_L^{n-p}L_o^p + L^n))$$
$$dB/dt = \mu_m BL^n/(K_L^{n-p}L_o^p + L^n) - K_d B \qquad (8)$$

where $n > 0$, $p > 0$ are the model's coefficients, as a rule $n >= p$.

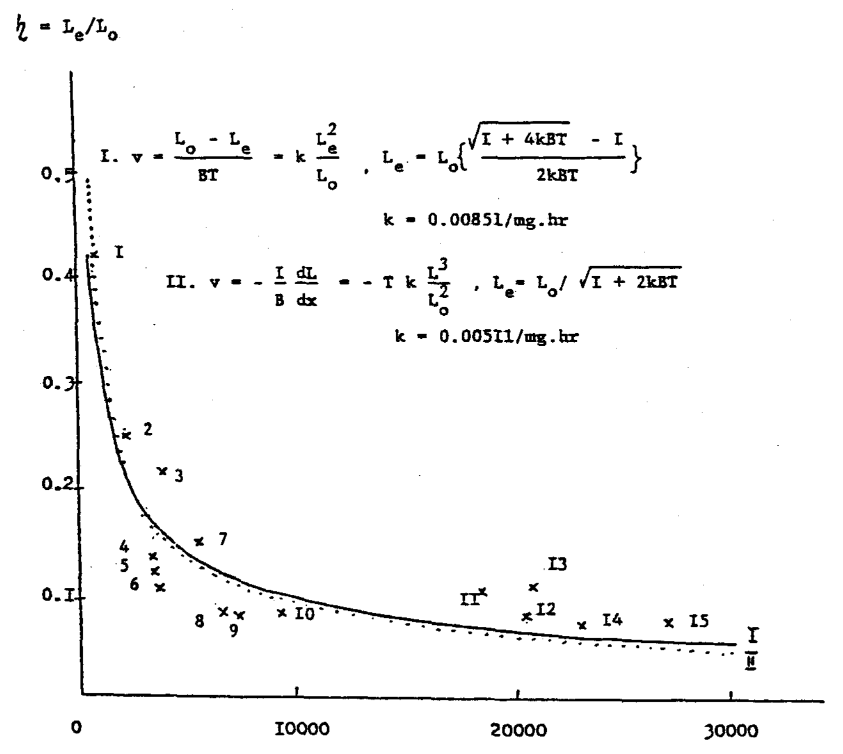

Fig.1.Dependence of $\alpha = L_e/L_o$ upon parameter $\beta = BT$ for 15 cities of USSR: 1.Pjatigorsk,1977; 2.Brjansk,1977; 3.Cheljabinsk,1976; 4.Rostov-on-Don,1978; 5.Saransk,1978; 6.Kujbjishev,1979; 7.Astrahan, 1976; 8.Sochi I,1977; 9.Jaroslavl,1978; 10.Sochi II,1977;11.Zhigulevsk, 1979; 12.Kalinin,1979; 13.Izhevsk,1978; 14.Gusj-Khrusyalnij,1979; 15.Orenburg,1978.

For real treatment systems the models mentioned above have usually a phenomenological nature and can be called as the formal "black-box" models. From the Fig.1 it is easy to see that the model of complete-mixing reactors gives the same results as the model of plug-flow reactors.
A smaller biomass retention time θ corresponded to a large value of the ratio BOD_5/COD in effluent water[2],which points to the reprocessing of relatively labile compounds.

3.THE MODELS OF BIOLOGICAL TREATMENT MECHANISM;All in all,it can be concluded that three hierarchic levels of the biological treatment processes can be discerned (Fug.2):culture of microorganisms (1),aggregates of microorganisms (2),community of microorganisms (3).

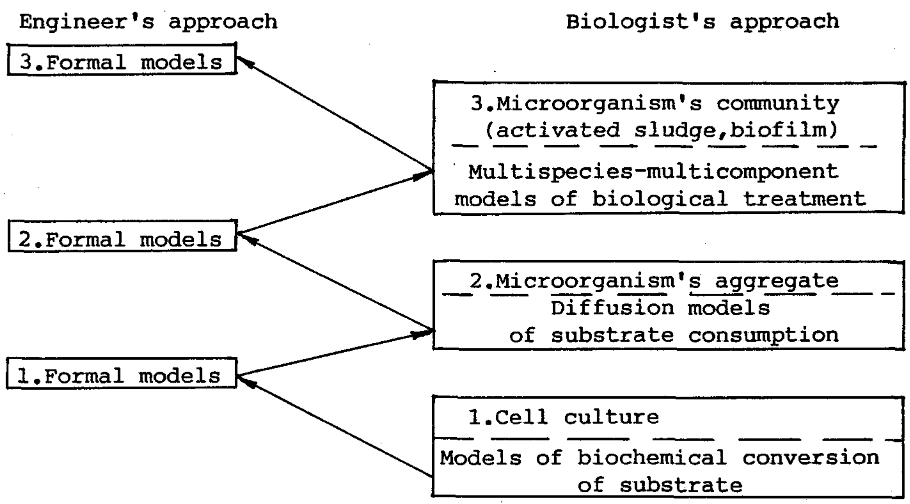

Fig.2. System of models discribing biological treatment processes.

Each of this levels can be described with a rather complex models,which would reflect the "mechanism" of respective phenomenon. At the same time,relatively simple formal models are also admissible. The models like (1)-(3) and (8) are some examples of such formal models.
The processes of physiological adaptation of the individual cells as well as the population shifts are very important for a biological treatment mechanism. Below we consider some models of population shifts in treatment systems under the variation of the biomass retention time θ.

3.1.THE CHEMOSTAT MODEL;The chemostate model for complete-mixing reactor can be written as

$$dS_i/dt = (S_{oi} - S_i)/T - \rho_{Si} \quad ,i = 1,2,\dots,N$$
$$dB_j/dt = \rho_{Bj} - B_j / \theta \quad ,j = 1,2,\dots,M \qquad (9)$$

where i is the ordinal number of substrate with concentration S_i; j is the ordinal number of different groups in heterogeneous biomass having concentration B_j;S_{oi} are the input concentration of substrates; T is the waste water retention time in the reactor.
The rates of substrate utilization ρ_{Si} and biomass growth rate ρ_{Bj} have the formes

$$\rho_{Si} = \sum_{j=1}^{M} \mu_{mj} B_j r_{ij} S_i / (Y_{ij}(K_j + \sum_{i=1}^{N} r_{ij} S_i)) \tag{10}$$

$$\rho_{Bj} = B_j (\mu_{mj} \sum_{i=1}^{N} r_{ij} S_i / (K_j + \sum_{i=1}^{N} r_{ij} S_i) - K_{dj}) \tag{11}$$

where μ_{mj} is the maximum specific growth rate of j th biomass group; K_{dj} is the dying and autooxidation rate constant for j th group; K_j is the respective half-saturation coefficient; r_{ij} is the prefarability of i th substrate to j th biomass group; Y_{ij} is the yield coefficient for j th group using i th substrate.

Let us introduce total biomass concentration and summary pollutant concentration

$$B = \sum_{j=1}^{M} B_j \quad , \quad L = \sum_{i=1}^{N} S_i \tag{12}$$

The corresponding equations for a total biomass and summary pollutant concentration are written as

$$dL/dt = (L_o - L)/T - \rho_L$$

$$dB/dt = \rho_B - B/\theta \tag{13}$$

where

$$\rho_L = \sum_{i=1}^{N} \rho_{Si} \qquad \rho_B = \sum_{j=1}^{M} \rho_{Bj}$$

The model (13) is a traditional model for the description of biological treatment in activated sludge system with complete-mixing aeration tank. But usually function ρ_L and ρ_B are used in Monod's form.

For steady-state conditions of model (9) we have

$$\mu_j = \rho_{Bj^*} / B_j^* = \rho_{B^*} / B^* = \mu = 1/\theta \tag{14}$$

where B_j^* and B^* are the corresponding stationary concentrations.

The biomass groups having

$$\mu_{mj} < \mu = 1/\theta \tag{15}$$

is not settled in the total biomass composition. The condition (15) is discussed, for example, by Downing and Knowles[4].

For $N = 1$ we have the special case of only one substrate and many biomass groups. Introducing the critical biomass retention time

$$\theta = \theta_{crj} = 1 / (\mu_{mj} S/(K_j + S) - K_{dj}) \tag{16}$$

one can write the conditions for settlement of j th biomass group, like we have got in (4)-(7). Only one biomass group with the largest value of a specific biomass growth rate

$$\mu_j(S) = \mu_{mj} S/(K_j + S) - K_{dj} = 1/\theta \tag{17}$$

will be in a biomass composition. Then the biomass composition is determined by the value of substrate concentration S, which, in-turn,depends on a biomass residence time θ. When influent substrate concentration S_o is changed the biomass composition can be changed too.

So,the substrate consumption rate is dependent on influent pollutant concentration. Such phenomenon reflect the changing of biomass composition under changing of influent pollutant concentration. The same phenomenon can be obtained from the models with heterogeneous biomass and mixed substrate. The example is shown in Fig.3.

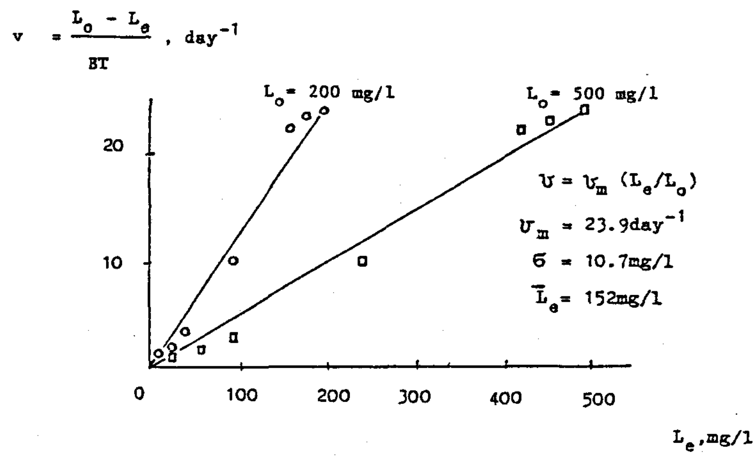

Fig.3.Dependence of treatment rate v on the summary effluent pollutant concentration L_e and its approximation by Grau's model. o , ▫ - results,obtained with help of the multi-component/multi-species model (9) at the definite values of coefficients.

3.2.THE TURBIDOSTAT MODEL;Instead of system (9) now we write a following system of differential equations

$$dS_i/dt = (S_{oi} - S_i)/T - \rho_{Si} \ , \ i = 1,2,\ldots,N$$

$$dB_j/dt = \rho_{Bj} - \sum_{m=1}^{M} \rho_{Bm} B_j/B^* \ , \ j = 1,2,\ldots,M \tag{18}$$

where $B^* > 0$ is a constant. It is easy to get from system (18) the equation for total biomass concentration

$$d\,B\,/\,d\,t = \rho_B\,(\,1\ -\ B\,/\,B^*\,) \tag{19}$$

So,the value $B = B^*$ is a stationary concentration of total biomass. At $\rho_B > 0$ the stationary value $B = B^* = \sum_{j=1}^{M} B_j^*$ will be stable. In

fact,the model (18) is a turbidostat model of biological treatment,where the steady-state concentration of a total biomass are kept as a constant $B = B^*$. Practically,the turbidostat operation conditions for activated sludge system were discussed by Gaudy and

Gaudy[6].

3.3.BIOMASS GROWTH RATE AND POLLUTANT CONSUMPTION RATE; Let us consider the systems (9) and (18) with the functions (10) and (11) at Y_{ij}=Y=const and K_{dj}= K_d = const. Then we get the equation where a specific growth rate of total biomass μ is a function on a specific summary pollutant utilization rate $v = (L_o - L_e)/BT$

$$\mu = 1/\theta = Y v - K_d \qquad (20)$$

The equation (20) is traditional for a description of biological treatment processes[9]. But in general case the coefficients Y_{ij} and K_{dj} are not the same. For example, the K_d value decreases at large θ [7]. This phenomenon can be explained as a non-viable biomass accumulation in activated sludge composition as well as the population shifts or physiological adaptation of individual microorganism's cells.

4.CONCLUDING REMARKS; As a result of modelling approach it is quite understandable that under variation of a biomass retention (turn-over) time θ as well as under variation of substrates loading v there are some population shifts. At small θ (large v) a microorganism's community is simplified. In this case the trophic chaines will be shorter,the quantity of species presented is decreased and some substrates goes through the treatment systems without consumption. At large θ (small v) a community becomes more complex and more inertial to environmental conditions changing. Many difficuly-to-decay substrate and some metabolic products are consumed.
In the fixed-film reactors a spacial separation of the different biomass groups becomes possible according to the changing of the θ value. The slower-growing species are displaced to the "outlying" space.
Under the population shifts the consumption rate of summary pollutant can be dependent on an influent pollutant concentration.

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