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CONSTRUCTION AND FITTING OF THE MODEL OF MOVING-BED BIOFILM REACTORS SYSTEM

In the paper, a model consisting of four biofilm reactors was described. The model was developed to simulate the process of integrated nitrogen and carbon removal. It was fitted based on the results obtained in an identical laboratory system. AQUASIM program was used in the simulations. As a result, a good fitting between calculations and measurements was obtained.

1. INTRODUCTION

Development of a mathematical model of wastewater treatment process is one of the first steps of its optimisation, which should improve the efficiency of the system investigated and allows determining its working parameters. Such a model enables also better understanding of biochemical and transport processes. Analytic model comprises numerous theoretical dependencies, making it possible to calculate the output variables as the functions of an input. This paper describes constructing and fitting a model of moving-bed biofilm system for the removal of nitrogen and carbon.

2. PROGRAM USED TO MODEL DEVELOPMENT

The model described in this paper was developed based on AQUASIM program. This program allows us to diagnose and simulate laboratory, technical and natural aquatic systems. The mathematical model of biofilm in this program is one-dimensional and is based on one-dimensional law of conservation of mass, volume and energy [3], [6]. It describes the density of particulate components and the concentration of matter dissolved in biofilm, advective and diffusive flux of mass, the conversion rates of particulate and dissolved biofilm components and the changes in

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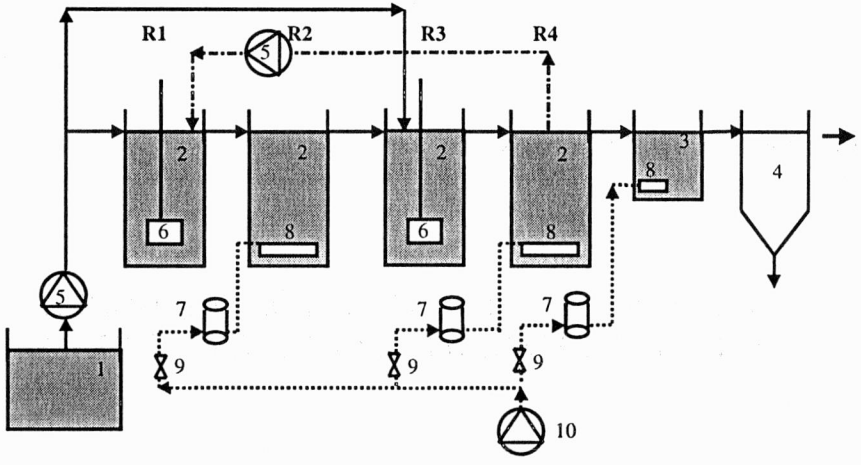

Fig. 1. Laboratory-scale set-up: 1 – tank with wastewater, 2 – reactor, 3 – activated sludge contact tank, 4 – settler, 5 – peristaltic pump, 6 – stirrer, 7 – rotameter, 8 – membrane tube diffuser, 9 – manual valve, 10 – air blower

biofilm thickness. The program user can choose the elements of the system, define its components, processes and links between the elements. The elements of the system are defined by means of those variables which have to be defined as the first. Then biochemical processes should be defined, and finally reactors and links between them [3]. The program contains procedures of simulation, parameters estimation, sensitivity analysis and error analysis. It works in Windows system [1], [3], [4].

3. MODEL DESCRIPTION

The model developed was identical to the laboratory system in which nitrogen and carbon removal was investigated. The system consisted of four reactors, in the first and the third ones denitrification took place, while in the second and the fourth ones – nitrification (figure 1). In this system, biomass was growing on moving carriers made of polyethylene, whose density ranged from 0.92 to 0.96 kg/dm^3. They were shaped as cylinders (about 9 mm in diameter and 7 mm in height). The tests were carried out using synthetic wastewaters comprising the following components: ammonium chloride, sodium acetate and dihydrogenphosphate and bicarbonate buffer.

In the model developed, five components dissolved were separated in the liquid phase. They were as follows: ammonium nitrogen (S_{NH}), peroxided nitrogen (sum of nitrates and nitrites, S_{NO}), dissolved oxygen (S_O), soluble biodegradable organic compounds (S_S) and inert organic compounds (S_I). In a solid phase of biofilm (biofilm matrix), the biomass of autotrophic bacteria, heterotophic bacteria and inert biomass were separated.

It was assumed that in a certain reactor at a given time a biofilm has homogeneous structure and the same thickness on all carrier elements. Mass flux within the biofilm results from molecular diffusion. The flux of particulate components within the biofilm was neglected, but a diffusion boundary layer between the biofilm surface and the liquid was taken into account. In the model, the changes in the biofilm composition were also taken into account. In each reactor, each group of microorganism was assumed to differ in the density. The changes in the biofilm thickness were also foreseen by conditioning the rate of biofilm detachment by the rate of its growth. Based on the Monod equation, five biochemical processes, i.e. the growth of aerobic heterotrophs, the growth of anoxic heterotrophs, the growth of aerobic autotrophs, the decay of heterotrophs, the decay of autotrophs, were taken into consideration. Kinetics and stoichiometry of nitrogen and carbon removal were based on the model of OLLSSON and NOWELL [2], but they supplemented it with inert biomass. The dependence of the growth of autotrophs and heterotrophs and the rates of their decay on the temperature was calculated using a simplified Arrhenius equation.

4. MODEL FITTING

The aim of model fitting was to establish such values of its parameters that allowed a faithful representation of a real system. The process of fitting of the model was divided into an initial and a basic fitting. During the initial fitting the wastewater stream being recirculated from the last reactor was replaced with wastewater stream whose concentration was consistent with the concentration measured. This enabled us to fit the subsequent reactors of the system and to improve gradually the consistency

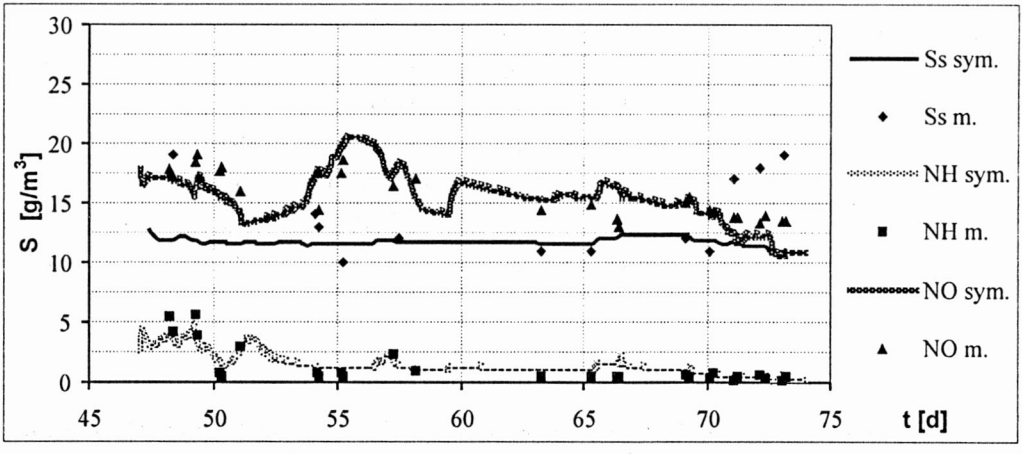

Fig. 2. Results of simulations and experimental data at the system outflow
(m. – measurements, sym. – simulations)

of simulation results with experimental data. This consistency as well as the influence of the parameters being changed were estimated visually or by means of χ^2 test. Basic fitting was carried-out using AQUASIM program which made possible parameter estimation (simplex method). Several parameters were fitted simultaneously and three calculation cycles were performed. In the last cycle, the system was modified in order to make it consistent with the experimental arrangement (i.e. with recirculation). Calculation results and measurement specification for the most important fitting phases and the selected parameters are given in table 1 and table 2. The results of investigations and simulations at the outflow of the system are presented in figure 2.

Table 1

Values of selected parameters

Characteristics		Symbol	Units	Literature values	Initial fitting	Basic fitting
Maximum growth rate of heterotrophs		μ_H	dm^3 /d	6	9	14.3
Maximum growth rate of autotrophs		μ_N	dm^3/d	0.25	0.23	0.93
Rate constant of decomposition for heterotrophs		b_H	dm^3/d	0.4	0.3	0.3
Rate constant of decomposition for autotrophs		b_N	dm^3/d	0.15	0.07	0.07
Anoxic reduction factor		η_d	–	0.6	0.7	0.79
Yield of heterotroph biomass in aerobic conditions		Y_{Ht}	g COD/g COD	0.8	0.6	0.70
Yield of heterotroph biomass in anoxic conditions		Y_{Ha}	g COD/g COD	0.54	0.3	0.33
Yield of autotroph biomass		Y_N	g COD/g N	0.24	0.07	0.070
Saturation constant for biodegradable organic compounds		K_S	g COD/m^3	4	1	23.4
Density of heterotrophs	R1	ρ_H^1	kg COD/m^3	100	103	131
	R2	ρ_H^2	kg COD/m^3	20	15	15
	R3	ρ_H^3	kg COD/m^3	150	70	240
	R4	ρ_H^4	kg COD/m^3	50	40	41
Density of autotrophs	R1	ρ_N^1	kg COD/m^3	100	50	59
	R2	ρ_N^2	kg COD/m^3	20	52	47
	R3	ρ_N^3	kg COD/m^3	150	50	54
	R4	ρ_N^4	kg COD/m^3	50	100	101

5. RESULTS

The best fitting of the simulation results to the results of measurements was obtained for ammonium nitrogen compounds. For peroxided nitrogen the fitting was slightly worse. For organic compounds the consistency of calculations with measurements was the weakest. The differences between the concentrations measured and calculated for the R1, R2

and R4 reactors were similar, but for the R3 – the greatest. This may be due to disregarding such processes as, for example, biochemical reactions, the biofilm destruction or detachment from a carrier as well as the changes in hydrodynamic conditions, changes in the model. They influenced such biofilm parameters as: thickness, density, diffusion coefficient and mass transfer coefficient. It should be stressed that real biofilm parameters are enormously variable [5]. Assuming that the biofilm thickness and the density are the same on all carrier elements in the reactor, we make a considerable but indispensable simplification, which can be the reason for the above-mentioned differences.

Table 2

Synthetic specification fitting results

Variable	Sample size	Test χ^2				Basic fitting		
		Literature parameters	Initial fitting	Basic fitting	Level $p(\chi^2)$	Participation χ^2 [%]		
S_{NH}^{1}	27	96.7	56.7	69.2	1.5e-5	4.8		R1 21.8
S_{NH}^{2}	27	4392.9	88.9	87.2	2.9e-8	6.2	S_{NH}	
S_{NH}^{3}	27	2202.2	44.7	49.4	0.005	3.5	15.8	
S_{NH}^{4}	27	10181.1	42.2	17.6	0.915	1.3		R2 24.6
S_{NO}^{1}	27	317.7	101.8	71.3	7.3e-6	5.0		
S_{NO}^{2}	25	3901.0	328.6	89.0	4.2e-9	6.3	S_{NO}	
S_{NO}^{3}	27	288.7	158.9	117.3	3.2e-13	8.2	25.7	R3 29.4
S_{NO}^{4}	26	3711.7	147.9	87.6	1.3e-8	6.2		
S_{S}^{1}	13	10624.0	2518.8	168.7	3.4e-29	12.0		
S_{S}^{2}	13	139.4	473.1	177.6	5.2e-31	12.1	S_S	R4 23.7
S_{S}^{3}	13	11219.9	563.4	235.7	5.9e-43	17.7	58.0	
S_{S}^{4}	13	185.3	304.2	227.6	2.8e-41	16.2		
S_{O}^{1}	21	1.2	3.5	3.4	0.99	0.2	S_O	S_O
S_{O}^{3}	12	6.8	10.6	4.2	0.98	0.3	0.5	0.5
Sum	298	47268.6	4843.7	1405.7	–	100	100	100

A high density of heterotrophs in the R1 and R3 reactors was obtained as a result of parameter estimation. It may have been caused by the settlement in these reactors of such groups of organisms which are characterized by the ability to form compact colonies or to form biofilm of highly variable thickness [5]. Low density of heterotrophs in the R2 and R4 testify to the development of the colonies of a dendriform or a filamentous structure, which has been noticed in microscopic examinations. This is typical of the development of these organisms in aerobic conditions. It should be also stressed that a density in the R2 lower than in the R4 is connected with a higher substratum loading of the former. The density of autotrophs in the R1, R2, R3 reactors differed imperceptibly. Twice as great density of these organisms in the R4 could be explained by different growth conditions (limiting the growth by lack of substratum).

In further works, more attention should be paid to the changes of biofilm parameters and processes relevant to biological removal of phosphorus.

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BUDOWA I KALIBRACJA MODELU UKŁADU REAKTORÓW Z RUCHOMYMI NOŚNIKAMI BIOMASY

Opisano budowę modelu układu czterech reaktorów z biofilmem, utworzonego do symulacji procesu zintegrowanego usuwania azotu i węgla. Jako narzędzia do przeprowadzania obliczeń użyto programu AQUASIM. Model kalibrowano, wykorzystując wyniki pracy identycznego układu w skali laboratoryjnej. W wyniku przeprowadzonych prac uzyskano dobre dopasowanie danych pomiarowych do obliczeń.

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