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BIOLOGICAL TREATMENT OF WASTE WATER: THEORETICAL BACKGROUND AND EXPERIMENTAL RESEARCH

Abstract. Recent years have seen a rising interest in biofilters. This is due to the application of new materials for particles in the charge and small energy expenditures. Biological purification before other methods has a number of significant advantages. Microorganisms complete the decomposition of domestic sewage to neutral products (gas and water), while ensuring the circulation of substances in nature. Thus, biological purification, unlike other methods, does not extract and does not transfer contamination to other forms, which ensures practically no-waste production. At the same time, biological methods are less expensive, since, with the exception of capital investments, they almost do not require operating costs. All methods of biological purification are mainly divided into aerobic and anaerobic. In aerobic method, microorganisms use dissolved oxygen in waste water, while in anaerobic process, microorganisms do not have access to oxygen.

The further development of the bio-purification technology will be promoted by the elaboration of effective methods for simulating the processes in purifying plants.

In the present paper, a model for calculating the bio-purification in a continuous reactor supported by experiments on a laboratory facility is developed. Below, instead of empirical assumptions about the exponential dependence of the decrease in the substrate concentration on the distance from the inlet to a reactor with parameters having no clear physical meaning and determined from experiments, this law is calculated directly with the use of the kinetics and mass transfer.

Key words: biofilm, water purification, modeling, biofilter.

Introduction

Environmental biotechnology uses microorganisms to improve environmental quality. This improvement includes preventing the discharge of pollutants into environment and cleaning up the contaminated mediums.

Nowadays there are sorbents, both natural, and artificial, which allow to clear waters from variety of pollutants simultaneously, for example from ions of heavy metals and petroleum. Below we explore a modified sorbent based on the use of one of a sol – gel process [1].

One of them is the biological treatment. Microorganisms capable of water remediation occur in nature as suspended flocs and attached biofilms. Flocs are formed without a solid substratum, while biofilms adhere to a solid substratum, i.e. on the surface of minerals.

Biofilms, which are naturally immobilized cells, occur ubiquitously in nature and are increasingly important in processes used in pollution control, such as trickling filters, rotating biological contactors and anaerobic filters. On the surface of the granules, microorganisms form a film into which the water-dissolved contaminants diffuse to serve as substrates for microbial proliferation.

A mathematical modelling by a biofilm under steady state conditions is discussed. The nonlinear differential Equations in biofilm reaction is solved using the Adomian decomposition method [2].

Biofilters are used successfully in cleaning water from various pollutants [3-5].

In works [6-8] some modern methods of sewage treatment are presented. However, in these works, water purification is not related to the activity of living microorganisms, which is characteristic of biological water treatment technologies.

The analysis of traditional (nitrification-denitrification) and the latest biotechnology wastewater from inorganic nitrogen has been done. Current status of the present key technologies of nitrogen removal from wastewater has been formulated. The main advantages and disadvantages of these biotechnologies are described in [9].

Biofilm formation and adherence properties of bacterial strains commonly found in wastewater treatment systems were studied in pure and mixed cultures using a crystal microtiter plate assay. These results on attachment and biofilm formation can serve as a tool for the design of tailored systems for the cleaning of municipal and industrial wastewater [10].

The stable effective operation of the biofilter is determined by a number of factors both promoting reproduction of microorganisms (conditions of the biochemical reaction, transport intensity of impurities and metabolic products) and inhibiting this process (film erosion by water flow, filling of charge pores, inhibition of bio-reactions by products of their own vital activity).

The further development of the bio-purification technology will be promoted by the elaboration of effective methods for simulating the processes in purifying plants.

In the paper, a model for calculating the bio-purification in a continuous reactor supported by experiments on a laboratory facility is developed. This approach was proposed in describing the processes proceeding in the biofilm [11].

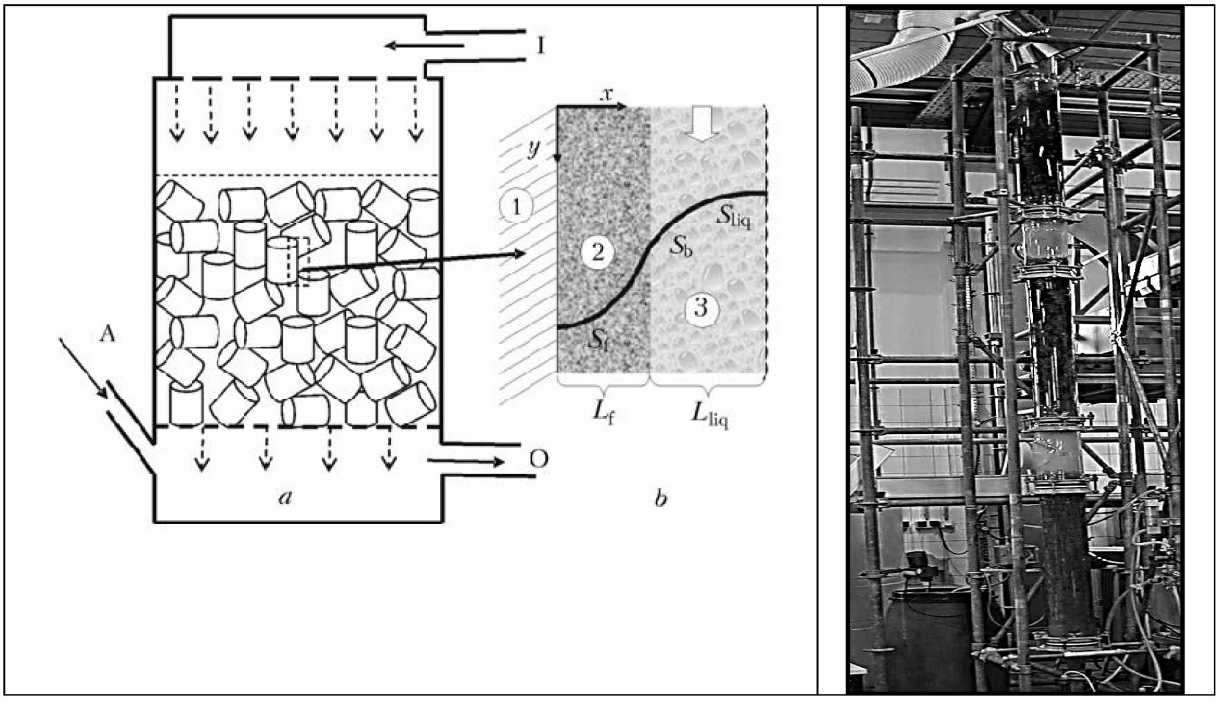

Figure 1 -Schematical representation of the water purification process:
a) biofilter: I, inflowing water; O, outflowing water; A, air inflow;
b) part near the ring surface: **1)** ring; **2)** biofilm of thickness L_f; **3)** water film of thickness L_{liq}. **c)** Laboratory-scale plant

Experimental facility

Below we describe measurements of the efficiency of purification of an artificially prepared water representing a low-concentration meat broth (the total inlet content of carbon in the aqueous solution was varied from 5 to 58 mg / l). Experiments were performed on a drop biofilter representing a vertical pipe

(Fig.1) with a working section length equal to 268 cm. The diameter of the pipe was 15 cm. The charge grains represented Raschig rings of height 1.67 mm, inner diameter 1.23 cm, and outer diameter 1.47 cm. Water was supplied to the reactor through a sprinkler in the form of a downflow of drops equidistributed over the reactor cross-section, and the trickling filtrate was removed upon reaching the bottom hole. Microorganisms on the particle surface represented mixed cultures.

Samples of water were taken at both the reactor inlet and outlet and also at two other points at a distance of 78 and 173 cm from the inlet.

The following indices were measured:

1. Total organic carbon. Hard balls of the biofilm carried out by the flow were filtered off from the samples, and the water was investigated for the total organic carbon with the use of a TOC-analyzer of the Groeger&Obst company (Germany).

2. Specific mass of the biofilm. At the same sampling points as for the analysis of water, ten rings were taken out. The weight difference of rings covered with the biofilm and without it gives the mass of the biofilm. Knowing the surface of the rings and measuring the biofilm density, we determined its total volume. On the assumption of a uniform distribution of the biofilm over the surface of the rings its average thickness was calculated.

MODEL OF WATER PURIFICATION IN THE BIOFILTER

Water running down in the biofilter flows over the biofilm surface on particles (Fig. 1a). The flow rate of water is selected so that it flows around the porous charge grains in the form of film and there is enough air between grains to provide aerobic microorganisms with oxygen.

1. Through the biofilm-water layer interface transport of the substrate into the biofilm occurs, so that in the direction of the flow (y) the substrate concentration in the water decreases:

$$Q_2 \frac{dS_1(y)}{dy} = -\beta_w \left(S_1(y) - S_b(y)\right), \tag{1}$$

where the value of the substrate concentration on the biofilm surface S_b is not known in advance.

2. The distribution of the substrate concentration in the biofilm is described by the equation

$$D_f \frac{\partial^2 S_f}{\partial x^2} = q \frac{S_f}{K + S_f} X_f \tag{2}$$

with the boundary conditions:

$$\frac{\partial S_f}{\partial x} = 0 \text{ at } x = 0, \text{ and } \beta_w \left(S_1 - S_f(L_f)\right) = D_f \frac{\partial S_f}{\partial x} \text{ at } x = L_f,\ S_1(L_f(y)) = S_b(y). \tag{3}$$

The biomass production rate is equal to the death rate of microorganisms taken, as in proportional to the squared concentration of the active biomass:

$$Yq \frac{S_f}{K + S_f} X_f = bX_f^2 \tag{4}$$

Equations (2) and (4) lead jointly to the relation

$$D_f \frac{d^2 S_f}{dx^2} = \frac{q^2 Y}{b} \left(\frac{S_f}{K + S_f} \right)^2 \tag{5}$$

3. The biofilm thickness is determined by the equality of the production rate of biomass across the whole width and the rate of its ablation:

$$\frac{Yq}{\rho} \int_0^{L_f} \frac{S_f}{K + S_f} X_f dx = rL_f \tag{6}$$

In view of (4)–(6) the biofilm thickness is defined as

$$L_f = \frac{Y}{r\rho}\beta_w (S_1 - S_b), \quad (7)$$

A major quantity found from the calculation is the quantity of substrate taken up from the water by the film.

Finding the diffusion flow of the substrate into the film $J = D_f \left.\frac{dS_f}{dx}\right|_{z=L_f}$ from Eq. (5) at the boundary conditions (3) and equating it to the substrate flow from the water into the film $J = \beta_w (S_1(y) - S_b)$, we obtain equations for finding S_b.

Analysis of problem (3), (5) shows [12], that two reaction regimes can be distinguished: 1) in a relatively thick film, substrate consumption occurs not across its whole width, but only in the water-contacting layer (diffusion regime, unsaturated biofilm); 2) a relatively thin film is saturated with substrate due to the diffusion and its consumption occurs across its whole width at an approximately equal rate (kinetic regime, saturated biofilm).

For calculations, the following diffusion kinetic parameters were taken: $D_{liq} = 0.8$ cm^2/day, $D_f = 0.64$ cm^2/day, K =0.01 mg/day, $q = 8$ days^{-1}, $Y = 0.5$, $b = 0.5$ cm^3/(day/mg), $R_{col} = 7.5$ cm, $R = 0.6775$ cm, $H = 1.67$ cm, $\varepsilon = 0.704$.

COMPARISON OF CALCULATIONS AND MEASUREMENTS

Calculations were performed with varying rate of substrate flow through the reactor Q and substrate concentration $S_{liq}(0)$ in water at the reactor inlet (column at $y = 0$). Measurements were made at the Q values given in the Table1.

Table 1 - Various variants of the flow velocity measurements

Variant number	1	2	3	4	5	6	7	8	9
Q, cm/min	3.28	4.47	5.26	5.32	5.82	5.89	6.56	10.63	11.32

The change in $S_{liq}(y)$ along the working channel of the biofilter was measured.

Figure 2 presents the results of the calculations (curves) and the experimental values (dots) for all variants of the values of substrate flow rates given in table 1. In all cases, there is a fairly good agreement between the experimental and calculated data.

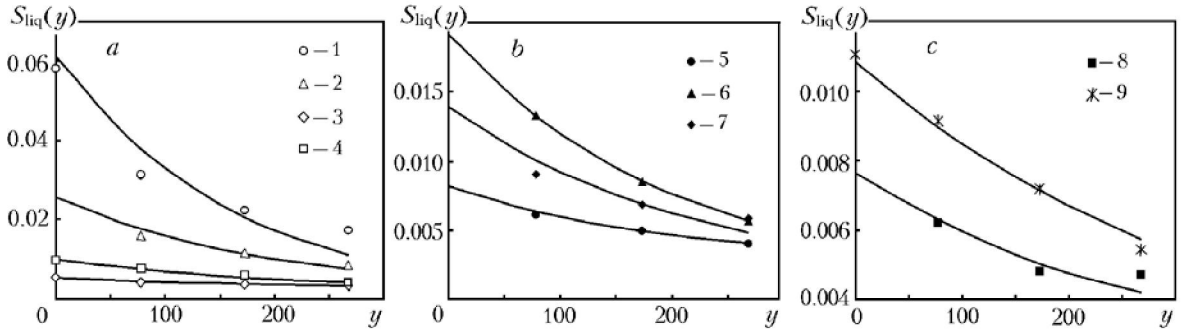

Figure 2 - Substrate concentration in the liquid $S_{liq}(y)$ versus the distance y down the bioreactor column (curves show calculations, dots — experiments): a) relatively low flow rates of the substrate solution; b) moderate flow rate of the substrate; c) relatively high flow rates of the substrate solution.

The curve number corresponds to the variant number in the table.

Both the experiment and the numerical calculation show that for high flow rates Q the efficiency of water purification, i.e., the ratio between the carbon concentrations at the reactor outlet and inlet,

decreases. This is likely to be due to the reduction of the residence time of the substrate solution in the reactor in spite of some increase in the mass transfer intensity.

The calculations provide an additional possibility of judging the behavior of other, not measured, variables defining the process of water purification such as the substrate flow into the biofilm and the biofilm thickness in each section of the biofilter.

However, comparison between measured and calculated thicknesses of the biofilm (Fig. 3) does not always give a satisfactory result for several reasons, including the following ones:

1. Modeling of the biofilm as a smooth layer characterized by the thickness alone is obviously insufficient. Models describing two-dimensional films are rather complicated and are under development [13].

2. Measurements were taken after about a weak upon variation of the feed rate of the substrate solution or its concentration. During this time, probably, the microflora concentration and, accordingly, the substrate flow in the film manage to adjust themselves to the new conditions, and the corresponding change in the biofilm thickness strongly depends on the erosion intensity and requires much more time.

3. Measurements of the thickness of the biofilm through measurements of the mass or its volume may not be accurate enough, since they do not take into account the non-uniformity of the film distribution over the surface of grains.

It is important to know the film thickness, because this characteristic correlates with the substrate flow into the film. Figure 3 shows the curves reflecting the change in the biofilm thickness along the working channel of the biofilter. It is seen that the biofilm thickness decreases with decreasing concentration of the substrate in the liquid flow.

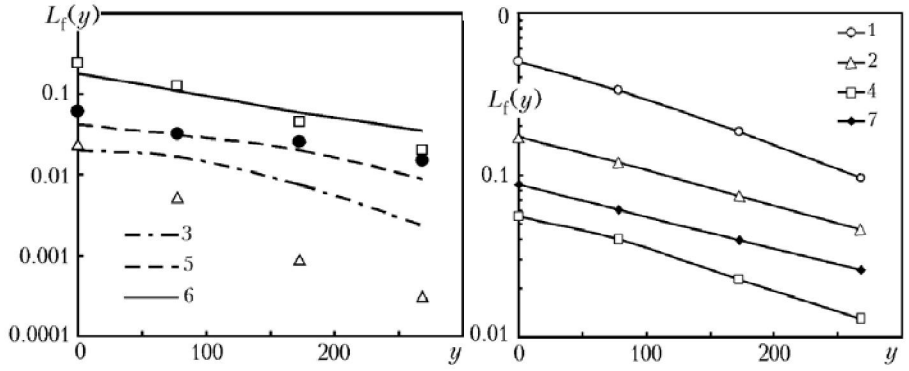

Figure 3 - Comparison of some of the calculated and measured thicknesses of the biofilm L_f in various sections along the reactor y and under various flow conditions: 1, 2, 3, 4, 5, 6, 7) variant number. y, L_f, cm

The decrease in L_f with y happens due to the decrease in the substrate concentration in water. On the other hand, a decrease in L_f leads to a decrease in the working volume of the biofilm, which in turn decreases the intensity of water purification.

Conclusions

The developed theoretical model of water bio-purification in the biofilter agrees well with the experimental data obtained on a laboratory bio-column. The agreement between calculations and measurements of the decrease in the substrate concentration down the column is much better than the corresponding comparison for the film thickness.

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АҚАБА СУЛАРДЫ БИОЛОГИЯЛЫҚ ӨҢДЕУ: ТЕОРИЯЛЫҚ НЕГІЗДЕРІ ЖӘНЕ ЭКСПЕРМИЕНТТІК ЗЕРТТЕУЛЕР.

Аннотация. Бұл жұмыста ағынды реакторда биологиялық тазартуды есептеу үшін теориялық модель ұсынылған. Модель су ағынындағы контаминанттардың көмірсутектері субстрат ретінде қызмет атқаратын, биопленканың түзілуін есепке алуға негізделген. Есептеулер тазарту процесі кезінде биопленканың өсуін қамтамасыз ететін, Рашиг сақиналарымен толтырылған зертханалық түтікті реакторда жүргізілген эксперименттермен жасалды.

Ағынмен шығарылған, биопленканың қатты бөлшектері үлгілерден сүзілді, және су сынама алуға арналған төрт нүктеден алынып, Groeger & Obst (Германия) фирмасының ТОС-анализаторын қолданып, жалпы органикалық көміртегінің құрамына зерттелді.

Биопленканың меншікті салмағы анықталды. Дәл сол су сынамасы алынатын нүктелерден он сақина қайтып алынды. Биопленкамен жабылған сақиналардың салмағының айырмашылығы, биопленканың салмағын береді. Сақинаның бетін біліп және биопленканың тығыздығын өлшей отырып, біз оның жалпы көлемін анықтадық. Сақиналардың бетінде биопленканың біркелкі екендігін ескеріп, оның орташа қалыңдығы есептелді.

Биофильтраттағы суды биологиялық тазартудың теориялық моделі зертханалық биоколоннада алынған эксперименттік деректермен жақсы үйлеседі. Пленка қалыңдығымен салыстырғанда, колонна бойындағы субстрат концентрациясының азаюының өлшемдері мен есептеулері арасындағы сәйкестік әлдеқайда көп.

Түйін сөздер: биопленка, суды тазарту, модель, биофильтр.

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БИОЛОГИЧЕСКАЯ ОБРАБОТКА СТОЧНЫХ ВОД: ТЕОРЕТИЧЕСКАЯ ОСНОВА И ЭКСПЕРИМЕНТАЛЬНЫЕ ИССЛЕДОВАНИЯ

Аннотация. В данной работе предложена теоретическая модель для расчета биоочистки в проточном реакторе. Модель основывается на расчёте образования биопленки, субстратом для которой служат углеводороды контаминантов в потоке воды. Расчёты сопровождались экспериментами на лабораторном трубчатом реакторе, заполненном кольцами Рашига, на которых в процессе очистки нарастала биоплёнка.

Твердые частички биопленки, вынесенные потоком, отфильтровывались из образцов, и вода в четырёх точках отбора проб исследовалась на содержание общего органического углерода с использованием TOC-анализатора фирмы Groeger & Obst (Германия).

Определялась удельная масса биопленки. В тех же точках отбора проб, что и для анализа воды, изымалось по десять колец. Разница в весе колец, покрытых биопленкой и без нее дает массу биопленки. Зная поверхность колец и измеряя плотность биопленки, мы определили ее общий объем. В предположении равномерного распределения биопленки на поверхности колец была рассчитана её средняя толщина.

Разработанная теоретическая модель биоочистки воды в биофильтре хорошо согласуется с экспериментальными данными, полученными на лабораторной биоколонне. Согласие между расчетами и измерениями падения концентрации субстрата вдоль колонны намного лучше, чем при соответствующем сравнении толщины пленки.

Ключевые слова: биопленка, , очистка воды, модель, биофильтр.