DOI: 10.31073/mivg201801-121
Available (PDF): http://mivg.iwpim.com.ua/index.php/mivg/article/view/121
UDC 628.16:552.546

METHOD OF ENGINEERING CALCULATIONS OF BIOREACTORS FOR BIOLOGICAL TREATMENT OF NATURAL WATER AND ADVANCED TREATMENT OF SEWAGE

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Abstract. *The system "bioreactor (BR) – contact clarifying filter (CCF)" of biological water purification with various impurities in it in the case of direct water flow through successively interacting structures is analyzed. The method of engineering calculations of the BR that provides saturation of water with oxygen, gases removal from water, and biochemical oxidation of impurities present in the input water, with the help of microorganisms immobilized on fibrous filtering load, is developed.*
Key words: *bioreactor, biological film, fibrous loading, substrate concentration, porosity of loading, water quality*

Formulation of the problem. In order to intensify the processes of natural and sewage treatment in agricultural water supply and sewage systems, a number of measures have been proposed, some of which are the use of biological methods of water purification with the help of attached hydrobionts in fine-fiber loading bioreactors, as well as gravity forces in the ascending movement of the coagulated water through floating filtering boot.

For the first time, raised the question of the expediency of microbiological methods for purification of natural waters, Professor P.I. Carnation [2], which claims that the microbiological method can purify any contaminated water, significantly improve the efficiency of water purification, improve the quality of purified water and reduce its cost.

Currently, biological methods are widely used for purification of natural and wastewater treatment [3-5]. With the biological method of neutralizing underground waters, the specific iron bacteria Gallionella ferruginea, due to their catalytic action, quickly oxidize Fe_2, and the resulting iron hydroxide Fe $(OH)_3$ accumulate in a compact form, which significantly increases the dirt content of the KPF and the duration of the filtracycle.

Features of the installation with BR and KPF. A water treatment plant for purifying natural or purifying sewage (Figure 1) works like this [6]. Output water through the pipe 1-through the aerator 2 is fed to BR with a fibrous load 4, which is fixed between the grate bars 5. When spraying water in the aerator 2 into small droplets and falling from the height not less than 0.5m water is saturated with oxygen, which is used by microorganisms immobilized on a fibrous charge, for the oxidation of impurities present in the source water.

BR has the following functions:

– biochemical oxidation of impurities present in the source water;

– removal of gases from the water to eliminate bubble colmatation in the subfilter space 8 KPF;

– ensuring a constant rate of water filtration during the filtration cycle due to an increase in the water level in it when the loss of pressure on the KPF from hf.0 (at a clean loading) to hf.max. (at the end of the filter cycle).

The KPF 7 undergoes a deep water purification during its ascending movement through foam polystyrene loading. In the subfilter space of this filter 8, a precipitate from the hydroxide group (in the purification of natural water) or active sludge (in the purification of wastewater) is accumulated in the subfilter space of this filter, which is additionally involved in water purification , which, after rising filtration through foam polystyrene loading, is collected by a cap drainage 12 and is discharged by pipeline 15 for further use.

The purified water corresponds to the normative parameters for the filter of this design and at a given rate of water filtration Vf, when the specific dirt content of the KPF is between Gb.min and Gb.max. The specific filtration of the filter for this rate of water filtration is called the amount of sediment that falls on 1 m^2 of filter area, kg/m^2.

When reaching the magnitude of Gb.max and its corresponding head loss in loading hf.max (Fig. 1), the KPF should be washed out. To do

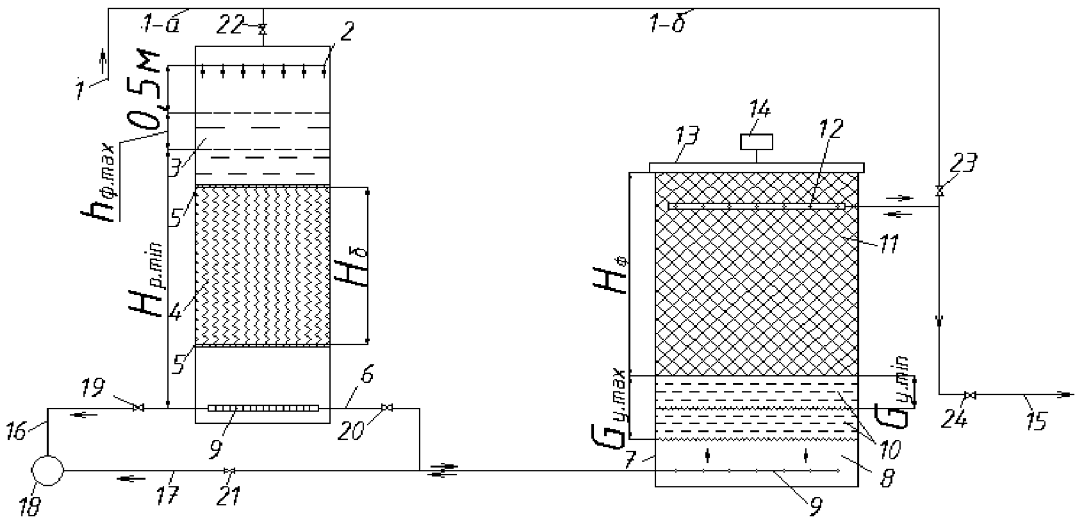

Fig. 1. Technological scheme of the installation for purification of natural or wastewater treatment:

1 – supply of outgoing water; 1-on BR; 1-b – for washing the KPF; 2 – aerator; 3 – BR; 4 – fine-fiber loading; 5 – grate bars; 6 – drainage of water to the KPF; 7 – KPF; 8 – subfilter space, 9 – drainage and water distribution system, 10 – sediment (active sludge); 11 – floating polystyrene filter loading; 12 – cap drainage; 13 – cover; 14 – hinge; 15 – removal of purified water; 16 – dumping sludge when washing BR; 17 – the same, when rinsing the KPF; 18 – the sewer pipe; 19 – 24 – latches

this, close the latches 20, 22 and 24 and open the latches 21 and 23. The washing water, moving from top to bottom through the foam polystyrene boot 11, washes out the excess sediment ΔG = Gb.max-Gb.min from the subfilter space and removes it through the drainage system 9 and pipeline 17 in the sewer pipe 18.

The flushing of the KPF with this intensity qпр must be performed during the estimated time tpr to ensure the standard quality of the filtered water in the next filter cycle of its operation.

The purpose of the research is to develop a method of mathematical modeling of processes of biological purification of natural and sewage water on bioreactors and methods of engineering calculations of these structures to determine their optimal structural and technological parameters.

The principle of the bioreactor. Microorganisms inhabiting a biofilm, which is formed on the surface of fiber fibers, oxidize substances that are in the source water, oxygen, thus obtaining energy for their life (Fig. 2).

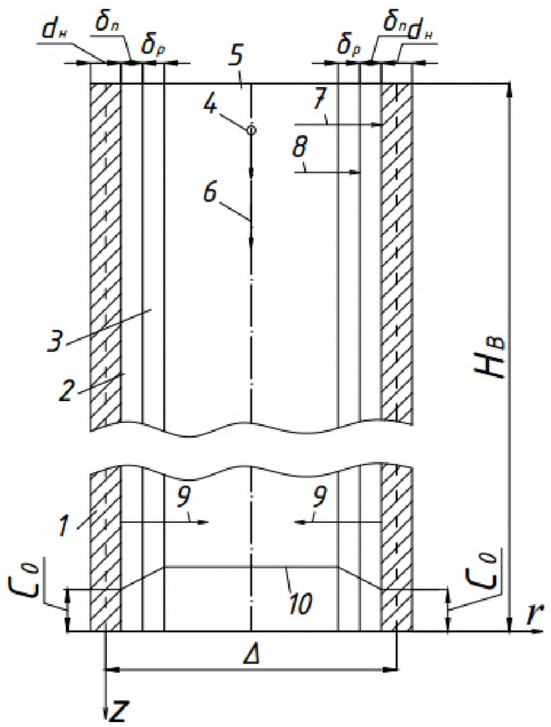

Fig. 2. Scheme of metabolism in the elementary layer of BR with fibrous loading:

1 – fibrous threads of loading; 2 – biological film; 3 – liquid film; 4 – impurities in the source water; 5 – the source water; 6 – direction of movement of water; 7 – admission of impurities to a biofilm; 8 – the flow of oxygen; 9 – removal of biological water purification products from biofilms; 10 – diagram of the distribution of pollution concentration; HB – length of filaments of fibrous loading; dn – diameter of fibers; δp and δr are the thickness of the biofilm and the liquid film respectively; Δ – the distance between the axes of the filaments in the fibrous loading

After intense aeration, the initial water enters the BR and is evenly distributed between the filamentous filaments, flowing around the surface on which the biofilm is formed with aerobic microorganisms. At the same time, processes such as adhesion, sorption, diffusion, destruction, oxidation, etc. occur, which results in the rapid removal of oxidized substances and the formation of new substances [7-9].

Mathematical model and algorithm of engineering calculations BR. For a mathematical description of water purification processes in the BR it is necessary to establish the balance of the change in the concentration of contamination in the biofilm, the liquid film and the volume of the source water, which is located between the fibrous filaments and moves from top to bottom (fig. 2).

Around the filament yarn 1 with diameter $d_н$, a biological film 2 with a thickness $\delta_р$ is formed, and a thin laminar layer 3 (liquid film) with thickness $\delta_г$ is formed near the surface of the biofilm.

The area of the biofilm in 1 m BR is determined by the formula:

$$F_б = \pi d_н N, \text{ м}^2/\text{м} \quad (1)$$

where N is the number of filaments in the BR, which depends on the shape of its cross-section (Fig. 3) and the distance between the axes of the filaments in the fibrous loading Δ:

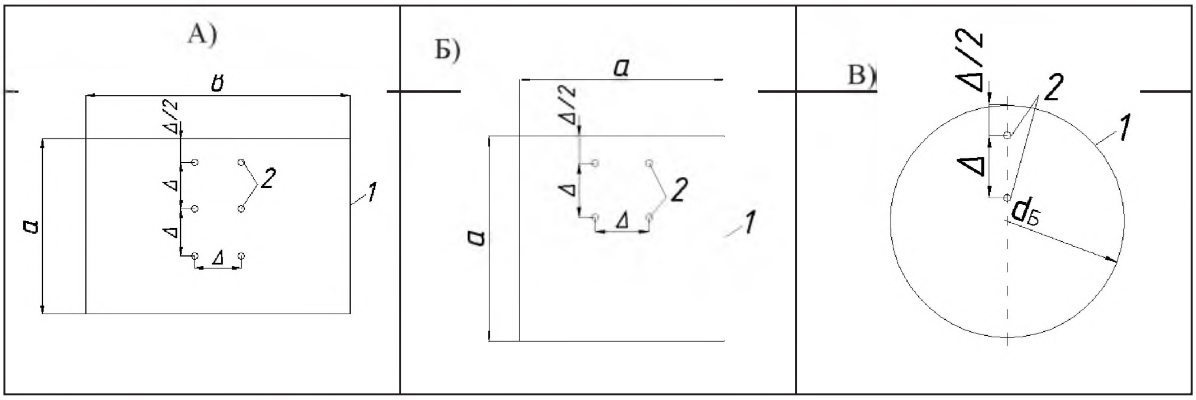

Fig. 3. Schemes of uniform placement of filament yarns in the cross section of BR:
A – rectangular shape; B – square form; B – cylindrical shape;
1 – building BR; 2 – fibrous filaments

The coefficients of packaging of BR with fibers are determined by the formulas [11]:

a) for BR of a rectangular shape

b) $$\alpha = \frac{\omega_H N}{ab} \cdot \frac{(a-\Delta)}{\Delta}\frac{(b-\Delta)}{\Delta} = \frac{\omega_H}{ab} \cdot \left(\frac{a}{\Delta}-1\right)\left(\frac{b}{\Delta}-1\right) \quad (2)$$

c) for BR of a square shape

d) $$\alpha = \frac{\omega_H N}{a^2} = \frac{\omega_H}{a^2} \cdot \frac{(a-\Delta)}{\Delta} = \omega_H\left(\frac{1}{\Delta}-\frac{1}{a}\right)^2 \quad (3)$$

c) for BR of a cylindrical shape

$$\alpha = \omega_H \left(\frac{1}{\Delta} - \frac{1}{d_б}\right)^2 \quad (4)$$

In these formulas: a and c are the dimensions of the sides of the cross-section BR of rectangular shape; db – diameter of cylindrical BR; Δ is the distance between the axes of the filament yarns; – cross-sectional area of one thread; N – number of threads in BR.

The porosity of the fibrous loading is determined by the formula:

$$P = 1 - \alpha \quad (5)$$

In the process of water filtration, the porosity of BR will change by expression

$$P_t = 1 - \omega_{Ht} / \Delta^2 = P_0 - \Delta P_t, \quad (6)$$

where P_0 and P_t are the porosity of BR in the beginning of the filtracycle and after t hours of its work; ΔPt-decrease of this porosity at time t as a result of overgrowing of filaments with biofilms; ω_{Ht} is the average cross-sectional area of one thread at this moment.

The value of ΔPt is determined by the formula:

$$\Delta P_t = \pi/4(\delta_{nt}/\Delta)^2, \quad (7)$$

where δ_{nt} is the thickness of the biological film around the yarn at the time t.

Since the sizes of BR: a, in and db (Fig. 3) are much larger values of Δ, after algebraic transformations, the area of the biofilm in 1 m BR can be determined by the formula:

$$F_б = \frac{\pi d_н \omega_б}{\Delta^2}, \quad (8)$$

where – cross-sectional area BR, m^2.

The required number of threads in the BR with the area with the accepted distance between the axes of threads Δ is determined by the formula:

$$N=\omega_б / \Delta^2, \quad (9)$$

or with a known number of threads N, the average distance between their axes should be:

$$\Delta=\sqrt{\omega_б / N}. \quad (10)$$

When compiling the equations of the material balance recorded in relation to the concentration of pollution, the changes of which occur in the BR, assumptions are adopted, described in the special literature [6, 7], which made it possible to obtain the following dependence:

$$P\frac{\partial C}{\partial t} = -V_ф \frac{\partial C_e}{\partial z} - \frac{KcFб}{\omega_б}(C_e - C_б) \text{g/(dm}^3\text{ hour)} \quad (11)$$

where Vf – velocity of water filtration in BR, m/h; P – porosity of filter loading BR; and – concentration of the substrate in the initial water, respectively, in the pore channels of the BR and on the boundary of the liquid film and the biofilm, g/m^3; and – change in the concentration of the substrate, respectively, in time and along the way of filtering water in the BR; Kc – coefficient of mass transfer of a substrate in a liquid film, m/h; – the total area of the biofilm BR with a height of 1 m, m^2/m; – cross-sectional area of BR, through which the source water moves, m^2.

The porosity of the fibrous loading is determined by the formula (6), and the area of the biofilm in 1 m BR – by the formula (8).

So, for BR with fiber-loaded filtering boot, you can write:

$$(1-\frac{\omega_H f}{\Delta^2})\frac{\partial C_e}{\partial z} - V_ф \frac{\partial C_e}{\partial z} \frac{K_c F_б}{\omega_б}(C_e - C_б) \text{g/(dm}^3\text{h)} \quad (12)$$

As a result of the solution of equation (12), a dependence is obtained for the determination of the substrate concentration on the height of the Hb filter:

$$C_{e(z,t)}=C_0 e^{-ž} \quad (13)$$

where C_0 – concentration of the substrate in the source water at the entrance to the BR, g/m^3; γ is the parameter characterizing the intensity of change in the concentration of the substrate at the boundary of the separation of films in the height of the BR:

$$ž=z\frac{A_0}{V_ф} \quad (14)$$

where A_0 is the parameter characterizing the conditions of biosorption in BR

$$A_0 \frac{K_c \pi d_н}{\Delta^2}\left(1-\frac{C_б}{C_e}\right), \text{hour}^{-1} \quad (15)$$

At the output of the BR z = H_0. Then:

$$C_ф= C_0 e^{-Ȟ_0} \quad (16)$$

$$H_б= H_б\frac{A_0}{Vф} \quad (17)$$

After recording the dependence (17) relative to Hb, we obtain the following expressions for determining the required height of BR Hb or with a known value Hb for determining the quality of the water $C_ф$, leaving the BR:

$$H_б=\frac{V_ф}{A_0} ln\frac{Co}{C_ф}, \text{ m} \quad (18)$$

$$C_ф=C_0/\exp\frac{A_0 H_б}{V_ф}, \text{ g/m}^3 \quad (19)$$

As we see from the formula (18), the required working height of the loading BR (Fig. 1) depends on the estimated depth of water purification $C_0/C_ф$, is directly proportional to the water filtration rate and is inversely proportional to the value of the parameter A_0, which is determined by the formula (15), which after transformations has the form:

$$A_0=AB, \text{ hour}^{-1} \quad (20)$$

where A – parameter characterizing the process of mass transfer between fibrous filaments BR:

$$A=Kc(1\frac{C_б}{C_e}-)\text{m/hour} \quad (21)$$

B is the parameter characterizing the geometric environment of the fibrous loading and is equal to the ratio of the length of the line around one load thread to the square of the distance between their axes:

$$B\ \frac{\pi d_н}{\Delta^2}=,\text{m}^{-1} \quad (22)$$

Consequently, with the increase in the number of threads per unit volume of fiber load, the value of Δ will decrease, that is, the parameters B and A_0 will increase, and the required height of BR according to formula (18) will be smaller.

Engineering calculations BR. BR perform the role of air separators, the area of which must be taken from the calculation of the velocity of the downstream water flow not more than 0,05 m/s and the duration of water in it for at least 1 minute [12].

The calculations are in the following sequence:

– for the estimated flow of water through the BR Q_P, m^3/hour, the accepted number of threads of fibrous loading N and the cross-sectional area of one thread, determine the cross-sectional area of BR:

$$\omega_б=\frac{Q_P}{180} + N\omega_h, \text{ m}^2 \quad (23)$$

and the velocity of water in the BR:

$$V\phi = Q_P \; / \; \omega_б \text{ м/год} \qquad (24)$$

– to ensure the required time for water in the BR with a duration of tr≥1h, its height should be no less (Figure 1)

$$H_{P.min} \geq \frac{Q_P t_p}{60\omega_б}, m \qquad (25)$$

At the limit velocity of water in the BR Vrr = 0,05m/s, this height should be not less than HP.min≥3 m;

– for preliminary calculations, we take the approximate values of the output constants and coefficients defined in the special literature [7, 8]: *Kc* = 0,025-0,080 m/hour; *A* = 0,01-0,04 m/hour; *δp* = 0,1-0,2 mm;

– determine the parameter B by formula (22), the parameter A_0 by the formula (20) and the value of Hb by the formula (18);

– according to laboratory studies, we find the maximum specific bristle content of BR, the duration of the filtracycle in the zone of accumulation of contaminants and the duration of washing BR in its given intensity;

– specify the estimated values of H_b and S_f and the efficiency of water purification in the BR.

Conclusions. The required working height of the loading BR depends on the depth of the water treatment $C_0/C_ф$, is directly proportional to the water filtration rate $V_ф$ and inversely proportional to the number of threads in the unit of loading БР.

The developed methodology of engineering calculations BR can determine their rational design and technological parameters, based on the requirements of providing the required time for water in the BR at the marginal velocity of the downward movement of water and the calculated efficiency of water purification from impurities.

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П.Д. Хоружий, С.Р. Стасюк, Я.Б. Мосийчук

Методика инженерных расчетов биореакторов для биологической очистки природных и доочистки сточных вод

Проанализирована система биологической очистки воды с различными примесями в ней при прямоточном движении воды через последовательно взаимодействующие сооружения: биореактор (БР) – контактный осветлительный фильтр (КОФ). Разработана методика инженерных расчетов БР для обеспечения процессов насыщения воды кислородом, удаление из воды газов и биохимического окисления примесей, находящихся в исходной воде, с помощью микроорганизмов, иммобилизованных на волокнистой фильтровальной загрузке.

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Методика інженерних розрахунків біореакторів для біологічного очищення природних і доочистки стічних вод

Проаналізовано систему біологічного очищення води з різними домішками в ній при прямоточном русі води через послідовно взаємодіючі споруди: біореактор (БР) – контактний прояснювальний фільтр (КПФ). Розроблено методику інженерних розрахунків БР для забезпечення процесів насичення води киснем, видалення з води газів і біохімічного окислення домішок, що знаходяться у вихідній воді, за допомогою мікроорганізмів, іммобілізованих на волокнистому фільтрувальному завантаженні.