The aerobic biological purification of the wastewaters from the organic contaminants (OC) in the aerotanks with the suspended and the fixed biocenosis

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Summary. The mathematical model and calculation methods of biological purification of the waste waters from organic contaminants (OC) in the aerotanks with the suspended (free flowing) biocenosis in the form of the flukes of the active sludge and with fixed biocenosis in the form of the biofilm generated on the surface of the additional loading are presented. The characteristic properties of the modeling and calculation of the purification in the aeration tank mixers and in the aeration tank with plug flow are considered.

Key words: biological purification, organic contaminants, model, aerotank, biofilm.

GENERAL QUESTIONS

In practice at the treatment of urban, domestic and similar in composition wastewaters the most widely are used the methods of the biological purification. The classical technological scheme of such purification is a system of the constructions the main component of which is the bioreactor – aerotank [5, 6, 15]. As is known in the aeration tank the removing (oxidation) of the adsorbed on the floating flakes the active sludge consisting mainly of the microorganisms suspended or dissolved in water organic contaminants (OC) is occurred. Recall that the activated sludge enters in the tank, where is released from the treated water and the part of which goes again for further treatment in the aeration tank. In more details the processes and mechanisms that occur in the biological purification of waste waters system aerotank – tank-regenerator are particularly described in [2, 7, 9, 11, 14].

Depending on the hydrodynamic regime of the liquid flow bioreactors aerotanks are divided into the aerotanks mixers and the aerotanks with plug flow [7, 14, 15]. So in the aeration tank mixer the waste waters, activated sludge and oxygen almost immediately are mixed with each other and therefore the concentration of the microorganisms and contaminants and dissolved oxygen are taken the same around the all reactor volume. In aeration tank with plug flow there is not the mixing and the waste water with activated sludge are moving in the reactor and in a result of the oxidation the concentration of pollutants decreases along the length of the reactor. Especially the decreasing is observed on the initial areas of the reactor. The rate of oxidation of contaminants and according to this the demand in oxygen can be non uniform along the length of the construction and therefore in practice the aerotanks with a plug flow with uniform and non-uniform aeration along the length of construction are used [13, 14].

The made analysis showed that the efficiency of removing of the OC in the aeration tanks especially with the recent increasing demand for quality of the treatment can be significally increased if before suspended biocenosis (activated sludge) to ensure in the volume of the aeration tank the arrangement of additional load in a form of the variety of nets, packing's and so on the surface of which the biofilm with a high concentration of the microorganisms is formed. If the mechanisms of the removing of the OC by the activated sludge are thoroughly researched and presented in particular in [1, 6, 7] then the removing of the OC by the fixed biocenosis in a form of the biofilm so extensively is studying in the filtration of the treatment fluid in the trickling and the submerged filters [3, 6 – 8, 10].

At this the dynamics of the biofilm formation on the surface of the loading and removal mechanisms of the OC by the biofilm are considered and studied noting the significant advantages the removing of the OC by the fixed biocenosis. According to experts such combined biological treatment of waste waters in the buildings with fixed and suspended biocenosis has a number of significant technological advantages and thus their efficiency can be significantly increased [6].

Taking into account of the above the analysis and evaluation of the joint removing of the OC by the suspended and the fixed biocenosis in the aerotanks mixers and aerotanks with plug flow the general mathematical model which is reduced to realization of the following material balance equations written relatively the changes in the concentration of organic contaminants in the aeration tanks L_a is presented. It is assumed that the process of biochemical oxidation is provided by the sufficient oxygen and oxygen is not limiting the kinetics of the biooxidation as suspended and the fixed biocenosis [6 – 8]:

$$\frac{\partial L_a}{\partial t} = D_a \frac{\partial^2 L_a}{\partial x^2} - V\frac{\partial L_a}{\partial x} - R, \quad (1)$$

$$R = \lambda_a N + \varepsilon R_a - \varepsilon R_c, \quad (2)$$

where R, R_a, R_c – speeds of the general reaction, utilization of OC by the suspended biocenosis (activated sludge) and extracted substances at the sludge dying off of the sludge respectively; N – stream (transport) of the OC through the surface biofilm for its utilization by the fixed biocenosis (biofilm); L_a – OC concentration in the aeration tank; D_a – diffusion coefficient (dispersion) in the liquid in the aeration tank; $V=Q_a/F$ – the average flow rate in the aeration tank; F – lateral aeration tank area; Q_a – flow rate in the aeration tank; l – working length of the aerotank; λ_a – constructive parameter;

$$\varepsilon = 1 - \frac{W_\delta}{W_a} = \frac{W_p}{W_a}, \quad (3)$$

W_a – working aeration tank volume; W_p – volume of liquid in aeration tank; W_δ – volume of the given load (packing) with a fixed biocenosis.

In practical calculations sufficiently to consider the equation (1) at the stationary conditions. In dimensionless form it looks as:

$$\frac{1}{Pe}\frac{\partial^2 L_a}{\partial \bar{x}^2} - \frac{\partial L_a}{\partial \bar{x}} - RT = 0, \quad (4)$$

where $\bar{x} = x/l$, $T=1/V$, $Pe=Vl/D_a$ – known diffusion criterion Peclet.

MODELING AND CALCULATION OF THE AEROTANK MIXER WITH THE SUSPENDED AND FIXED BIOCENOSIS

As are known the general material balance equation of pollutants in the aeration tank mixer has the form [6, 14]:

$$W_p \frac{\partial L_a}{\partial t} = Q_a(L_0 - L_a) - F_{\delta l} N - R_a W_p, \quad (5)$$
$$W_p = \varepsilon W_a, \quad F_{\delta l} = F_\delta l, \quad Q_a = Q_1 + Q_2,$$

where $F_{\delta l}$ – total surface area of biofilm (load) in the aerotank; F – area of biofilm surface per unit length of aeration tank l.

For practical calculations, equations (5) and (4) when $Pe << 1$ that is at significant values $1/Pe$ can be simplified to look like for ideal aeration tank mixer as:

$$L_0 - L_a - R_3 = 0, \quad (6)$$

where

$$R_3 = \lambda_a N - (R_a - R_c)T_a,$$
$$\lambda_a = \frac{F_{\delta l}}{Q_a}, \qquad T_a = \frac{W_p}{Q_a}. \quad (7)$$

In the future we will use equation (6), (7) for the development of engineering calculations.

Let us consider the following cases in depending on the location of the loading system in volume (area) of the aerotank cases.

1. Elements of load (parkings, nets, etc.) are located throughout the volume (length) of the aeration tank (Fig. 1). In this case, the area $F_{\delta l}$ will be a total surface area of loading in the aeration tank; $F_{\delta n} = \frac{F_{\delta l}}{W_a}$ – specific load area. In this case according to equation (6) removing of contaminants occurs in biofilm by the fixed biocenosis and in liquid aeration tank volume by the suspended biocenosis. To determine the contaminations by the fixed biocenosis it is necessary to determine the flow of pollutions that enter into the biofilm N:

$$N = -D_L \frac{\partial L}{\partial z} = K_L \left(L_a - L|_{z=0}\right), \quad (8)$$
$$L|_{z=0} = L_\delta,$$

where L, L_δ, L_a – OC concentrations in the biofilm, on the surface of the biofilm and in the aerotank respectively; D_L – coefficient of molecular diffusion in biofilm; K_L – mass-transfer coefficient of the OC in the liquid film.

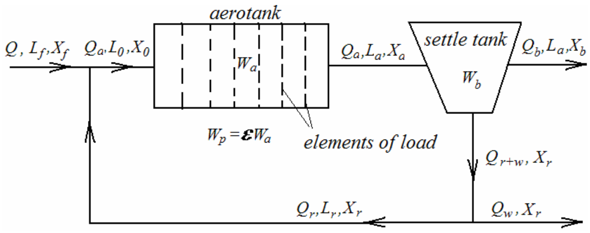

Fig. 1. Balance scheme of the aeration tank mixer with located completely fixed biocenosis

Depending on the type of the velocity of the kinetic reactions which are taken in the biofilm with fixed and suspended biocenosis (activated sludge) in the volume of the aeration tank consider the following variants (technological scheme) removing of OC in general.

As an example consider the case where the reaction rate in the biofilm is taken first order namely:

$$R_L = kL, \qquad k = \frac{\mu_m X}{Y K_{mL}} = \frac{\rho_m}{K_{mL}}, \quad (9)$$

and in the aeration tank – rate of reaction of zero order namely:

$$R_a = w_a, \qquad w_a = \rho_{ma} = \frac{\mu_{ma} X_a}{Y_a}. \quad (10)$$

Here μ_m, μ_{ma} – specific maximum rates of growth of the microorganisms in the biofilm in the aeration tank volume and X, X_a – concentrations of the fixed and suspended microbial biomass respectively; K_{mL} – saturation coefficient (halfamplification); $Y = dX/dL$ – stoichiometric coefficient of the growth of the biomass in the biofilm.

This technological scheme of treatment can be used in particular at the wastewater tertiary treatment by the fixed biocenosis after main treatment by the activated sludge in the aeration tank. The value of the stream of the OC through the biofilm surface N is determined in the result of the solution of the equation which characterizes the removing of the OC by the biofilm formed on the surface of the load material saturated by the microorganisms with concentration X :

$$D_L \frac{\partial^2 L}{\partial z^2} - R_L = 0 \qquad (11)$$

with boundary conditions: N at $z = 0$ and $\frac{\partial L}{\partial z} = 0$ at $z = \delta$. This solution was derived in [9] and allows you to determine the change in concentration throught of the biofilm thickness $L(z)$ and what is most important the necessary for further calculations concentration L_δ on the biofilm surface:

$$L_\delta = AL_a, \qquad (12)$$

where

$$A = \frac{1 + e^{-\varphi}}{\left(1 + e^{-\varphi}\right) + \lambda\left(1 - e^{-\varphi}\right)},$$
$$\varphi = 2\sqrt{\alpha}, \quad \alpha = \frac{k\delta^2}{D_L}, \quad \eta = \frac{\sqrt{kD_L}}{K_L}. \qquad (13)$$

According to (8) the flow of the OC into biofilm will be:

$$N = K_L L_a (1 - A) \qquad (14)$$

or [7]

$$N = -D_L \left.\frac{\partial L}{\partial z}\right|_{z=0} = D_L \frac{th\sqrt{\alpha}}{a_0} L_\delta = k_1 L_\delta,$$
$$k_1 = \frac{th\sqrt{\alpha}}{\alpha_0}, \qquad \alpha_0 = \sqrt{\frac{D}{k}}. \qquad (15)$$

Using equation (6) which in this case will looks like as:

$$L_0 - L_a - \lambda_1 L_a (1 - A) - T_a w_a = 0,$$
$$\lambda_1 = \frac{F_{\delta l}}{Q_a} K_L = \lambda_a K_L, \qquad (16)$$

we may obtain the dependence for determining of the concentration in the aeration tank L_a at the conditions of the removing of the OC by the fixed and suspended biocenosis:

$$L_a = \frac{L_0 - T_a w_a}{1 + \frac{F_{\delta l}}{Q_a} K_L (1 - A)} \qquad (17)$$

Taking into account of the recirculation regime and the process of dying the value of the concentrations X_a in the aeration tank in the formula (17) is taken according to next expression:

$$X_a = \frac{X_0}{1 - T_a(\mu_{ma} - b_a)}. \qquad (18)$$

The solution of the given technological scheme (see Fig. 1) is made also to the case when the reaction rates in the biofilm and in the aeration tank are taken to the first order namely according to the formula (9) in the biofilm and in the aeration tank to next formula:

$$R_a = k_a L_a, \qquad k_a = \frac{\mu_{ma} X_a}{YK_{ma}}. \qquad (19)$$

The more general case when the reaction rate R in the biofilm and in the aeration tank occurs according to with known nonlinear equation Monod is considered and realized namely:

in biofilm

$$R_L = \frac{\rho_m L}{K_m + L}, \qquad \rho_m = \frac{\mu_m X}{Y}, \qquad (20)$$

in aeration tank

$$R_{La} = \frac{\rho_{ma} L_a}{K_{ma} + L_a}, \qquad \rho_{ma} = \frac{\mu_{ma} X_a}{Y_a}. \qquad (21)$$

It will be note that in the equations (20) and (21) the possible influence of inhibiting action of the other substances is not included.

2. Aerotank consists of two parts which we assume are reactors 1 and 2. The first part is a reactor 1 in which removing of the OC is due to the fixed biocenosis that is formed on the mounted load, the second part – the reactor 2 in which removing of the OC is due with a help of the suspended biocenosis (activated sludge) that it works like a typical aerotank mixer (Fig. 2).

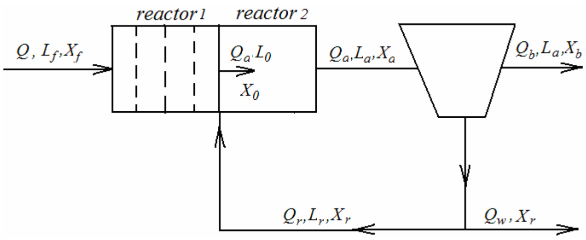

Fig. 2. Balance scheme of the aeration tank mixer with located in the reactor 1 fixed biocenosis

It will be note that in both parts of the aeration tank the reactors are operating under the scheme of the reactor mixer. Then according to the general equation for determining the concentration of the OC at the output of reactors 1 and 2 we will use the next equations:

for reactor 1

$$L_f - L_0 - \frac{F_\delta l}{Q} N = 0, \qquad (22)$$

for reactor 2

$$L_0 - L_a - T_a R_a = 0. \qquad (23)$$

That to determine the concentration L_0 at the outlet of reactor 1 more appropriate for the practice will be the solution of the equation (22) at the rates of the reactions in the biofilm of the zero-order and according to equation Monod. In determining the concentration L_a at the outlet of the reactor 2 (aeration tank) it is appropriate to consider the rate of reaction R according to the equation Monod. In this case the reactor 2 is regarded as aerotank mixer. Using equation (23) and obtained before the first case the dependences we may to determine the concentration L_a taking into account of the recirculation of the stream *r* and output parameters of the reactor 2 including the $T_a = T_{a2} = W_{p2}/Q_a$ and others.

3. As in the previous case aerotank mixer consists of the two parts (reactors) (Fig.3) but in this case the removing of the OC in reactor 1 is due to a suspended biocenosis (sludge) and it works like a normal aerotank mixer but in reactor 2 the removing of the OC is due to the fixed biocenosis on the established here load. Such technological scheme of treatment especially in practical terms will be appropriate according to the modern requirements which demand to more high degree of the purification when in the existing traditional aerotanks the tributary treatment of the waste waters are difficult and uneconomical.

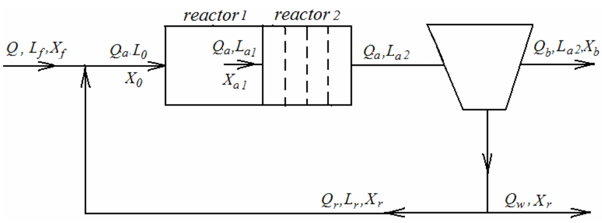

Fig. 3. Balance scheme of the aerotank mixer with located in reactor 2 fixed biocenosis

It will be note that in both parts of the aeration tank the reactors are working as the reactors mixers. According to the technological scheme on the Fig. 3 at the formation of the fixed biocenosis the activated sludge does not participate and passes without change through porous load that is in the volume of reactor 2 may be a slight removing of the OC due to the suspended biocenosis here (sludge) and it is not included. in the reactor 2 is necessary to the methodology developed for the first case (see Fig. 1).

In the result of the solution of the equations (6), (7) taking into account the characteristics of treatment in this technological scheme of the aerotank mixer were obtained the dependences to determine of the concentration of the OC at the output of reactors 1 and 2 taking into account of the effect the most appropriate and possible reaction rates of the removing of the OC. So on the output of the reactor 1 were obtained the dependences of the removing of the OC at the reaction rate of the zero-order and according to nonlinear equation Monod and on the output from the reactor 2 the dependences of removing of the OC at the reaction rates first order and to nonlinear equation Monod are proposed.

MODELING AND CALCULATION OF THE AEROTANK WITH PLUG FLOW WITH THE SUSPENDED AND FIXED BIOCENOSIS

As are known at the conditions of the aeration tank with plug flow the movement of the stream along of the length l of the aerotank with average velocity $\upsilon = \frac{Q_a}{F}$ is taking into account. Since in the real aeration tanks with plug flow the value $\frac{1}{p_e} = \frac{D_a}{\upsilon_e}$ <0,0002 according to [13, 14] then in the engineering calculations to determine the concentration L_a along the stream x the equation (4) can be simplified and written as for ideal aeration tank with plug flow $\left(p_e \to \infty, \quad \frac{1}{p_e} \to 0 \right)$ in the next form:

$$-\upsilon \frac{\partial L_a}{\partial X} - R = 0, \qquad \upsilon = \frac{Q_a}{F} \qquad (24)$$

in which the velocity of the overall realization of the OC utilization by the fixed biocenosis in the view of the biofilm formed on the load and by the suspended biocenosis in the form of the active sludge in the liquid of the aeration tanks has the form:

$$R = \lambda_2 \left(L_a - L|_{z=0} \right) - \varepsilon R_a + \varepsilon R_{Cl}, \quad (25)$$

$$\lambda_2 = \frac{F_\delta}{F} K_L, \quad \varepsilon = \frac{W_p}{W_a},$$

where F_δ – the surface area of loading (biofilm) per unit length of aeration tank where is arranged the load; $F = \frac{Q_a}{\upsilon}$ – area of the aerotank; υ – the average flow rate in the aeration tank.

That to solve the equation (24) we must to find a concentration on the surface of the biofilm $L|_{z=0} = L_\delta$, in according to the adopted equations of the possible reactions of the removing of the OC in the biofilm and in the aeration tank R_a and dying(selfoxidation) of the sludge R_C. The value of concentration L_δ on the biofilm surface for the reactions of the first order and in the equation Monod can be defined by the formula (12), which may be get by solving equation (11) and for zero-order reaction according to the next formula:

$$L_\delta = L_0 - \frac{\omega_m \delta}{K_L}, \qquad \omega_m = \frac{\mu_m X}{Y} \quad (26)$$

Let us consider the possible technological schemes of the work of the aeration tank with plug flow with the fixed and suspended biocenosis.

1. Elements of the load (parking's, nets, etc.) are uniformly spaced along the length l of the aeration tank. So in this case the removal of the OC by the fixed biocenosis with the total surface area $F_{\delta l} = F_\delta l$ and the suspended biocenosis (activated sludge) in fluid volume $W_p = \varepsilon W_a$, where $W_a = Fl$ – the total volume of the aeration tanks and

$\varepsilon = 1 - \dfrac{W_\delta}{W_a}$, where W_δ – the volume of the loading.

Let us consider the case where removing of the OC in the biofilm and in the aeration tank (volume W_p) is occurring according to the reaction of the first order:

$$R_L = kL, \qquad R_a = k_a L_a. \qquad (27)$$

After some changes with taking into account to the reactions (27) we may to write the equation (24) in this case as:

$$-\frac{\partial L_a}{\partial x} - L_a(A_* + k_{a*}) = 0, \qquad (28)$$

where

$$A_* = \frac{\lambda_2}{\upsilon}(1 - A), \;\; k_{a*} = \frac{k_a}{\upsilon}, \;\; \lambda_2 = \frac{F_\delta}{F} K_L.$$

In the result of the solution of the equation (28) with the boundary condition at the inlet of the aeration tank $x = 0$, $L_a = L_0$, we will receive dependence for determining of the changes in the concentration L_0 along the length of the aeration tank:

$$L_a(x) = L_0 e^{\tilde{x}} = e^{-B\tilde{x}}, \qquad (29)$$

where

$$\tilde{x} = (A_* + k_{a*})x = B\bar{x}, \qquad \bar{x} = \frac{x}{l},$$
$$B = l(A_* + k_{ax})\bar{x}.$$

At the output of the aeration tank at $x = l$, $\bar{x} = 1$, we have:

$$L_a(l) = L_0 e^{-\tilde{l}} = L_0 e^{-B}, \quad \tilde{l} = B. \qquad (30)$$

Remind that received solutions are derived at the stationary conditions of the exploitation of the aeration tanks that come quickly enought.

The solution of the equation (24) for the most used in practice event when the removing of the OC in the biofilm and in the volume of liquid in aeration tanks W_p is occurred for more accurate reaction according to the famous equation Monod namely according to the equations in the biofilm R_L (20) and in the volume of the liquid of the aeration tank R_a (21).

The iterative methodic of the calculation to solving of the equation (24) with reactions (20) and (21) the content and the sequence of which is given in [10] was proposed.

In the technological scheme on the Fig. 1 it is possible also the case when removing of the OC by the fixed and the suspended biocenosis occur on the base of various kinetic reactions R, for example, by the suspended biocenosis (activated sludge) for the reaction according to the equation Monod and by the fixed biocenosis (biofilm) for reaction of the first order or vice versa. The calculation of the $L_a(l)$ on the output of the aeration tank is also occurred according to the general equation (30) in this case in which the iterative process is used in the calculation of the reaction occurring to the equation Monod in the volume of the liquid in the aeration tank.

2. Technological scheme aeration tank with the plug flow consists of two parts (reactors 1 and 2), in which in the one of them the removing of the OC is occurred with a help of the fixed biocenosis and in the second by the suspended biocenosis (activated sludge). As mentioned above the features of the removing of the contaminants will depend on their location along the length (in the plane) of the aeration tank in this case. Further consider the possible technological schemes of the aerotank with the plug flow.

1) The reactor with fixed biocenosis (biofilm) in length l_1 located in the first part of the aeration tank (reactor 1, see Fig. 2). In this case the removing of the OC in the reactor 1 is mostly occurred with a help of the fixed biocenosis (biofilm) on the load cells that are uniformly spaced along the length l_1 and is described by the equation:

$$-\upsilon_{a1}\frac{\partial L_{a1}}{\partial x}-\lambda_{21}(L_{a1}-L_1|_{z=0})=0,$$
$$\lambda_{21}=\frac{F_{\delta 1}}{F_1}K_{L1}, \quad (31)$$

where $F_{\delta 1}$ – surface area of the loading (biofilm) per unit length l_1; $F_{\delta l1}=F_{\delta 1}l_1$ – total surface area of the loading in the reactor 1.

The methodic for determining of the change of the concentration L_{a1} in length l_1 as a result we may as a result of the solution of the equation (31) (equation (28) at $k_{a*}=0$) at the boundary conditions $x=0$, $L_{a1}=L_f=L_0$. For the reactions of the first order and according to the Monod equation the solution for determining of the concentration $L_{a1}(l_1)$ at the outlet of reactor 1 will be as:

$$L_{a1}(l_1)=L_0 e^{-\tilde{l}_1}, \qquad \tilde{l}_1=l_1 A_{*1}, \quad (32)$$
$$A_{*1}=\frac{\lambda_{21}}{\upsilon_{a1}}(1-A_1).$$

The methodic of determining of the parameters A_1 is listed above and $\upsilon_{a1}=\frac{Q}{F_1}$ – average flow rate in the reactor 1 with flow area F_1 and rate of flow Q (see Fig. 2).

Since the effluents with a relatively large initial concentration $L_f=L_0$ come directly in the reactor 1 it would be also appropriate to consider the case of the removing of the OC in reactor 1 with a help of the biofilm according to the reaction of zero order:

$$R_{L1}=w_{L1} \qquad w_{L1}=\rho_{m1}=\frac{\mu_{m1}X_1}{Y_1}. \quad (33)$$

In the result of the solution of the above equation (11) that describes the removing of the OC by the biofilm for determining in this case the concentration $L_{\delta 1}$ we get:

$$L_{\delta 1}=L_{a1}-\frac{w_{L1}\delta_1}{K_{L1}}, \quad (34)$$

where δ_1 – average (estimated) thickness of the active biofilm in the reactor 1.

Then in the result of the solution of the equation (31) with the boundary conditions $x=0$, $L_{a1}=L_0$ and taking into account to the dependences (33) for determining of the changes in concentration along the length x of the reactor on the site l_1 we may get the next dependence:

$$L_{a1}(x)=L_0-\frac{F_{\delta 1}}{\upsilon_{a1}F_{a1}}w_{L1}\delta_1 x. \quad (35)$$

The concentration at the outlet of reactor 1 ($x=l_1$) will be as:

$$L_{a1}(l_1)=L_0-\frac{F_{\delta 1}}{\upsilon_{a1}F_{a1}}w_{L1}\delta_1 l_1. \quad (36)$$

At the possible presence in the reactor 1 the suspended biocenosis with regard to its added action the general equation to determine $L_{a1}(l_1)$ will looks like as:

$$L_{a1}(l_1)=L_0-\left(\frac{F_{\delta 1}}{F_1}w_{L1}\delta_1+w_{a1}\right)\frac{l_1}{\upsilon_{a1}}, \quad (37)$$

where $w_{a1}=\frac{\mu_{ma1}}{Ya_1}Xa_1$, Xa_1 – concentration of the suspended biocenosis in the reactor 1.

In the second part of the aeration tank reactor 2 length l_2 the removing of the OC is due to a suspended biocenosis (active sludge).

In this case in the reactor 2 for a supplying of the suspended biocenosis desired concentration X_{a2} which we assume is formed taking into account the recycling of active sludge and partly possible due to the detachment of the biomass from the biofilm the removing of the OC is described according to (24) the following equation at $\lambda_2=0$, $\varepsilon=1$:

$$-\upsilon_{a2}\frac{\partial L_{a2}}{\partial x}-R_{a2}+R_{c2}=0. \quad (38)$$

As the processes of dying will be taken into account in determining the concentration X_{a2} the results of the solution of equation (38) will depend on the accepted reaction of the removing of the OC R_{a2} in the reactor 2. In view of the fact that a considerable removing of the OC took place in the reactor 1 that in the reactor enters partially treated waste water the removing of the OC by the active sludge in the reactor 2 will mainly occurs through the actions of the reactions of the first order and according to the equation Monod. In this case the general equation (38) will looks like as:

$$-\upsilon_2\frac{\partial L_{a2}}{\partial x}-k_{a2}L_{a2}=0, \quad k_{a2}=\frac{\mu_{ma2}X_{a2}}{Y_{a2}K_{ma2}}. \quad (39)$$

The solution of equation (39) occurs at the boundary conditions $x=l_1$, $L_{a2}=L_{a1}(l_1)$ and taking into account the possible recycling by the coefficient r_2 we have:

$$L_{a2}=\frac{L_{a1}(l_1)}{1+r_2},\quad Q_{a2}=Q(1+r_2),\quad X_{a2}=\frac{r_2X_{Y2}}{1+r_2}. \quad (40)$$

Thus in the result of the solution of the equation (39) we obtain the following relationship for determining the change in concentration L_{a2} within the reactor 2 length $l_2=l-l_1$:

$$L_{a2}(x)=L_{a1}(l_1)\cdot e^{-(x-l_1)\frac{k_{a2}}{\upsilon_{a2}}},\quad \upsilon_{a2}=\frac{Q_{a2}}{F_2}. \quad (41)$$

In the case of $x=l$ in (41) we obtain the dependence of the concentration $L_{a2}(l)$ at the outlet of aeration tank:

$$L_{a2}(l)=L_{a1}(l_1)e^{-(l-l_1)\frac{k_{a2}}{\upsilon_{a2}}}=L_{a1}(l_1)e^{-\frac{k_{a2}}{\upsilon_{a2}}l_2}. \quad (42)$$

As are known the concentration of activated sludge $X_{a2}(l_1)$ includes a certain amount of silt that enters to the reactor 2 from the settling tank through recycling. However in this case from the reactor 1 may enters a certain amount of biomass that is detached from the biofilm, and will also take part in the removing of the OC. In [12] the balance equation is presented that can be used in general case to determine the change in concentration X_{a2} in the aeration tank with plug flow at the conditions of the removing of the OC with a help of the fixed and suspended biocenosis.

In case of the removing of the OC according to the reaction on the base of the Monod equation the equation (38) will looks like as:

$$-\upsilon_{a2}\frac{\partial L_{a2}}{\partial x}-\frac{\mu_{\max 2}L_{a2}}{K_{ma2}+L_{a2}}X_{a2}=0, \quad (43)$$

whose solution at the boundary conditions $x=l_1$, $L_{a2}=L_{a1}(l_1)$ in view of possible recycling coefficient r_2 has the general appearance according to (40):

$$-\frac{\mu_{\max 2}X_{a2}}{\upsilon}(x-l_1)=(L_{a2}-L_{a1}(l_1))+K_{ma2}\ln\frac{L_{a2}}{L_{a1}(l_1)}. \quad (44)$$

If takes in the equation (44) $x = l$ then to obtain the dependence which allows to determine the concentration at the outlet of the reactor $L_{a2}(l_2)$ at a known (given) length l_2:

$$l_2 = \frac{\upsilon}{\mu_{\max 2} X_{a2}} \times \left(L_{a1}(l_1) - L_{a2}(l_2) + K_{ma2} \ln \frac{L_{a1}(l_1)}{L_{a2}(l_2)} \right). \quad (45)$$

2) As in the previous case the aerotank witht the plug flow consists of two parts (reactors 1 and 2) but in the reactor 1 which is in the first part the removing of the OC is occured due to a suspended biocenosis (activated sludge) which means that it works in the regime of the aeration tank with the plug flow length l_1. In the second part (reactor 2) the removing of the OC is primarily occured due to the fixed biocenosis (biofilm) which is formed on the elements arranged here load. Placing in practice such technological scheme of the aeration tank with the plug flow in our opinion will be most appropriate since the placement in the second part the reactor 2 with the fixed biocoenosis allows significantly to improve the efficiency and quality of the treatment of the waste water, namely to ensure the purification of waste waters to the desired concentration.

Since to the reactor 1 directly enters to the treatment the waste waters of the significant concentration then consider the case of the removing of the OC by the activated sludge according to the reaction the zero order . Supplying of the sludge in the reactor 1 is occured due to recycling of the coefficient *r* according to the technological scheme shown in Figure 1. So in this case the general equation (38) will looks like as:

$$-\upsilon_{a1} \frac{\partial L_{a1}}{\partial x} - w_{a1}, \qquad w_{a1} = \frac{\mu_{a1} X_{a1}}{Y_{a1}}, \quad (46)$$

where as known

$$\upsilon_{a1} = \frac{Q_{a1}}{F_1}, \qquad Q_{a1} = Q(1 + r_1),$$

$$X_{a1} = \frac{r_1 X_Y}{1 + r_1}, \; L_0 = \frac{L_f}{1 + r_1}. \quad (47)$$

The solution of equation (46) takes at the boundary conditions $L_{a1} = L_0$ at $x = 0$ with the result of that we get:

$$L_{a1}(x) = L_0 - w_{a1} \frac{x}{\upsilon_{a1}}. \quad (48)$$

The concentration at the outlet of the reactor $L_{a1}(l_1)$ will be:

$$L_{a1}(l_1) = L_0 - w_{a1} \frac{l_1}{\upsilon_{a1}}. \quad (49)$$

If according to the above criteria's in the reactor 1 the removing of the OC by the activated sludge according to the reaction of the first order or the equation Monod that in this case we can to use the solution of the problem obtained for the technological scheme shown in Fig. 1. In this case in the general dependence (24) it is necessary to takes $\lambda_2 = 0$ that to exclude the action of the fixed biocenosis and replace the output parameters of the aerotank on the Figure 1 on the output parameters of the reactor 1.

In the second part of the aeration tank with the plug flow of the reactor 2 length l_2 the removing of the OC is occured mainly due to the fixed biocenosis (biofilm). In this case the features of the treatment in the reactor 2 (with biofilm) located in the second part of the aeration tank will depend on the technological scheme of the action of the reactor 1 with activated sludge. So in the technological scheme in which removing of sludge is occuring directly from the reactor 1 and it does not enter in the reactor 2 it can be assumed and accepted that the removing of the contaminants in the reactor 2 is occured only by the fixed biocenosis (biofilm). If the removing of the sludge from the reactor 1 is not happening and it enters with the waste water to the reactor 2 in this case at first it is necessary to take into account and to evaluate the degree of the removing of the OC through this sludge and at secondly to take into account the presence of sludge and the possible impact of it on the forminf of the structure of the biofilm and determining its parameters.

As a whole it can be assumed that according to the technological scheme in the reactor 2 is occuring predominantly the additional purification of the waste waters particularly treated in the reactor 1. If the additional purification of OC in the reactor 2 is occuring mainly by the fixed biocenosis (biofilm) then taking into account the reaction of the first order or the Mono equation it can be described by the following equation:

$$-\upsilon_{a2}\frac{\partial L_{a2}}{\partial x}-\lambda_{22}(L_{a2}-L_2|_{z=0})=0, \quad (50)$$

$$\lambda_{22}=\frac{F_{\delta 2}}{F_2}K_{L2},$$

where $\upsilon_{a2}=\frac{Q_{a2}}{F_2}$, $F_{\delta 2}$ – surface area of loading (biofilm) per unit length l_2; $F_{\delta l_2}=F_{\delta 2}l_2$ – total surface area of biofilm in the reactor 2 length l_2; Q_{a2} – flow that enters in the reactor 2.

In the result of the solution of the equation (50) with the boundary condition $x=l_1$, $L_{a2}=L_{a1}(l_1)$ to determine the changes in the concentration $L_{a2}(x)$ in length x where x varies from l_1 to l we get in general the next dependency:

$$L_{a2}(x)=L_{a1}(l_1)e^{-(x-l_1)A_{*2}}, \quad (51)$$

and to determine the concentration $L_{a2}(l)$ at the outlet of aeration tank (reactor 2) at $x=l$ we have a next dependency:

$$L_{a2}(x)=L_{a1}(l_1)e^{-(l-l_1)A_{*2}}=L_{a1}(l_1)e^{-l_2A_{*2}} \quad (52)$$

If according to accepted technological scheme from the reactor 1 to reactor 2 enters the activated sludge it must also take into account the partial removing of the OC by this silt in reactor 2. At this it is possible to limit this removing as in the case of the fixed biocenosis that is occurred due to the reaction of the first order.

So in this case the removing of the OC is occuring according to the technological scheme with a fixed biocenosis that corresponds the technological scheme of the treatment considered before and shown in Figure 1. In particular to determine the concentration $L_{a2}(l)$ at the outlet of the reactor 2 at the condition that the removing of the OC in it by the fixed and suspended biocenosis is occuring according to the reaction of the first order under (28) and concerning the reactor 2 of the length l_2 the next dependence is proposed:

$$\tilde{l}_2=(A_{*2}+k_{a*2})l_2, \quad k_{a*2}=\frac{k_{a2}}{\upsilon_2}, \quad (53)$$

$$L_{a2}(l)=L_{a1}(l_1)e^{-\tilde{l}_2}, \quad (54)$$

where

$$l_2=l-l_1, \qquad A_{*2}=\frac{\lambda_{22}}{\upsilon_2}(1-A_2),$$

$$\lambda_{22}=\frac{F_{\delta 2}}{F_2}K_{L2}.$$

CONCLUSION

Applying and calculations on the base of the proposed dependencies allow at a given geometrical and other characteristics to assess the impact of various factors on the processes of the treatment in various conditions of their work and make available the most economical and efficient in operating the biological reactor design.

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АЭРОБНАЯ БИОЛОГИЧЕСКАЯ ОЧИСТКА СТОЧНЫХ ВОД ОТ ОРГАНИЧЕСКИХ ЗАГРЯЗНЕНИЙ В АЭРОТЕНКАХ СО ВЗВЕШЕННЫМ И ПРИКРЕПЛЕННЫМ БИОЦЕНОЗОМ

Аннотация. Приведено теоретическое обоснование и методы расчета биологической очистки сточных вод от органических загрязнений (ОЗ) в аэротенках со взвешенным (свободно плавающим) биоценозом в виде хлопьев активного ила и прикрепленным биоценозом в виде биопленки, образованной на поверхности дополнительной загрузки. При этом рассматриваются особенности моделирования и расчета очистки в аэротенках-смесителях и аэротенках-вытеснителях.

Ключевые слова: биологическая очистка, органические загрязнения, модель, аэротенк, биопленка.