Analysis of Influence of External Factors on Processes of Biological Cleaning

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***Abstract*— The existing models of biocleaning do not consider influence of external factors therefore the work purpose − a research of temperature effect and pH on processes of a biological sewage disposal. Solvable tasks consist in the analysis of temperature effect of the external environment on behavior of models of a nitrification and denitrification. As a result of researches optimum conditions for development of a biocenosis of the fissile ooze which can be the basis for creation of mathematical ASM model are found.**

Keywords*— *biological cleaning; the fissile ooze; nitrfikation; denitrifkation; mathematical model operations; temperature

I. Introduction

Expansion of settlements, development of the industrial and agricultural production leads to increase in need for use of the potable, trade and process water. In this regard requirement in improvement of the existing methods and technologies of a sewage disposal or in development of new increases. The method of biological cleaning with the fissile ooze falls into to number of the most perspective and efficient. The ability of microorganisms of the fissile ooze to use a substratum as the power supply is the cornerstone of this method. In 1987 the group of researchers led by Mogens Henze offered the model for the systems of a sewage disposal called ASM1. It became a core for development of numerous models and their modifications, served as motivation for further researches and also promoted creation of a uniform notation in the field of model operation of a sewage disposal. The model is based on Herbert and Mono's basic models, i.e. describes processes of body height and disintegration of bacteria nitrifiers and denitrifiers. Besides, the model includes the mathematical description of process of oxidation, change of a causeticity and also hydrolysis of organic matter (decomposition of organic matter in water with formation of new connections) and an ammonification (rotting). Authors of model allocated process of a nitrification and denitrification of ASM1 that allowed to use only a part of the equations in the modified look. Bacteria autotrophs provide process of a nitrification in the presence of oxygen therefore ammoniyny nitrogen is oxidized to nitrate. Process of a denitrification is caused by effect of bacteria – geterotrof which in oxygen-free conditions delete nitric nitrogen, transforming it to gaseous.

II. The nitrifkation model taking into account temperature of the external environment

One of the main pollutants of sewage is compounds of nitrogen. Ammoniyny nitrogen, nitrites and nitrates concern them. Ammoniyny nitrogen is removed from water thanks to process of a nitrification as a result of activity of bacteria nitrifiers. The nitrification occurs everywhere in a habitat where nitrifying bacteria develop. At biological cleaning in the bioreactor nitrifier the simulated biocenosis from group of bacteria autotrophs – the organisms capable to synthesize organic matters from inorganic is created. Process consists of two stages. In the beginning ammoniyny nitrogen is oxidized oxygen to nitrite, then nitrite is oxidized to nitric nitrogen. At each stage process is exposed to influence of a certain group of bacteria nitrifiers. Within this research transformation of ammoniyny nitrogen to nitrate is considered without the transient state of nitrite. At the same time it is necessary that process of a denitrification is absent in the studied technological volume. Also it is supposed that are present at an entrance stream only ammoniyny and nitric soluble nitrogen. The basic processes accompanying a nitrification, sizes (reagents) participating in reaction their interference are characterized by conceptual model of a nitrification which can be presented in the form of the scheme provided the Fig. 1.

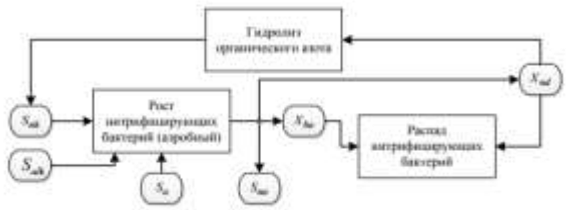

Fig. 1. Conceptual scheme of a nitrifkation

The processes entered on the scheme in rectangles communicate among themselves through the concentration of reagents represented in the form of ovals. The arrow directed from process (rectangle) to concentration of reagent (oval) means increase in this concentration as a result of this process. The arrow going from concentration of reagent to process answers decrease in this concentration. Concentration of solvends are designated by a symbol S, weighed – X.

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The mathematical model of a nitrification taking into account influence of a temperature factor is presented by the following set of equations:

$$\frac{dX_{ba}}{dt} = -\frac{dX_{ba}}{T} + (\mu_{\text{ma}}^{20°\text{C}} \exp^{\gamma(\theta-20)} \frac{S_{nh}}{S_{nh}+K_{nh}} \frac{S_o}{S_o+K_{oa}} - b_a)\, \text{X}_{ba};$$

$$\frac{dS_{nh}}{dt} = \frac{S_{nh}^{\text{вх}} - S_{nh}}{T} - \left(\frac{1}{Y_a} + i_{xb}\right) \mu_{\text{ma}}^{20°\text{C}} \exp^{\gamma(\theta-20)} \frac{S_{nh}}{S_{nh}+K_{nh}} \frac{S_o}{S_o+K_{oa}} X_{ba} +$$

$$+k_h X_{nd};$$

$$\frac{dS_{no}}{dt} = \frac{S_{no}^{\text{вх}} - S_{no}}{T} + \frac{1}{Y_a} \mu_{\text{ma}}^{20°\text{C}} \exp^{\gamma(\theta-20)} \frac{S_{nh}}{S_{nh}+K_{nh}} \frac{S_o}{S_o+K_{oa}} X_{ba};$$

$$\frac{dS_o}{dt} = \frac{S_o^{\text{вх}} - S_o}{T} - \left(\frac{4,57 - Y_a}{Y_a}\right) \mu_{\text{ma}}^{20°\text{C}} \exp^{\gamma(\theta-20)} \frac{S_{nh}}{S_{nh}+K_{nh}} \frac{S_o}{S_o+K_{oa}} X_{ba};$$

$$\frac{dX_{nd}}{dt} = -\frac{X_{nd}}{T} + i_{xb}(\mu_{\text{ma}}^{20°\text{C}} \exp^{\gamma(\theta-20)} \frac{S_{nh}}{S_{nh}+K_{nh}} \frac{S_o}{S_o+K_{oa}} - b_a) - k_h X_{nd};$$

$$\frac{dS_{alk}}{dt} = \frac{S_{alk}^{\text{вх}} - S_{alk}}{T} - \left(\frac{1}{7Y_a} + \frac{i_{xb}}{14}\right) \mu_{\text{ma}}^{20°\text{C}} \exp^{\gamma(\theta-20)} \frac{S_{nh}}{S_{nh}+K_{nh}}$$

$$\frac{S_o}{S_o+K_{oa}} X_{ba};$$

The name, designations and units of measure of the substances and parameters participating in process of a nitrification for the accepted model are provided in the table.

TABLE I. NAME, DESIGNATIONS AND UNITS OF MEASURE AND PARAMETERS FOR THE NITRIFKATS MODEL

Name of sizes and parameters	**Designation**	**unit of measure**
Concentration of bacteria nitrifiers	X_{ba}	g ХПК/m3
Concentration of the fluidized organic sluggish decomposed nitrogen	X_{nd}	g N/m3
Ammoniacal load	S_{nh}	g NH4+/m3
Concentration of nitric nitrogen	S_{no}	g NO3-/m3
Concentration of the dissolved oxygen	S_o	g NO2/m3
Causeticity	S_{alk}	equ/m3
Saturation constant on oxygen for autotrophs	K_{oa}	g O2/m3
Saturation constant on an ammonium at a nitrification	K_{nh}	g NH4+/m3
Fraction of nitrogen in biomass of the fissile ooze	i_{xb}	gN/g ХПК
Constant of disintegration of nitrifying bacteria	b_a	day^{-1}
The maximal coefficient of an increase of biomass for nitrifying bacteria	Y_a	g ХПК/g N
Hydrolysis constant in reaction of first order	k_h	day^{-1}
The maximal specific growth rate of autotrophs at 20 degrees Celsius	$\mu_{\text{ma}}^{20°\text{C}}$	day^{-1}
Temperature coefficient	γ	-
Ambient temperature	θ	°C

For a research of temperature effect of the external environment on processes of biological cleaning the temperature ranges specified in table 2 were accepted.

TABLE II. TEMPERATURE SCHEDULES

№ temperature schedule	**Increase of temperature, θ**	**Decrease of temperature, θ**
1	От 5°C до 15°C	До 15°C
2	От 10°C до 20°C	До 10°C
3	От 10°C до 30°C	До 10°C
4	От 20°C до 30°C	До 20°C
5	От 20°C до 40°C	До 20°C

As a result of computer model operation schedules according to Fig. 3 and 4 were received.

Apparently from the received schedules, the high-temperature mode 5 promotes the best body height of bacteria nitrifiers and according to decrease of concentration of oxygen, nitric and ammoniyny nitrogen and a causeticity. Fluidized organic nitrogen grows in result of body height of nitrifiers and decreases at lower temperature schedules.

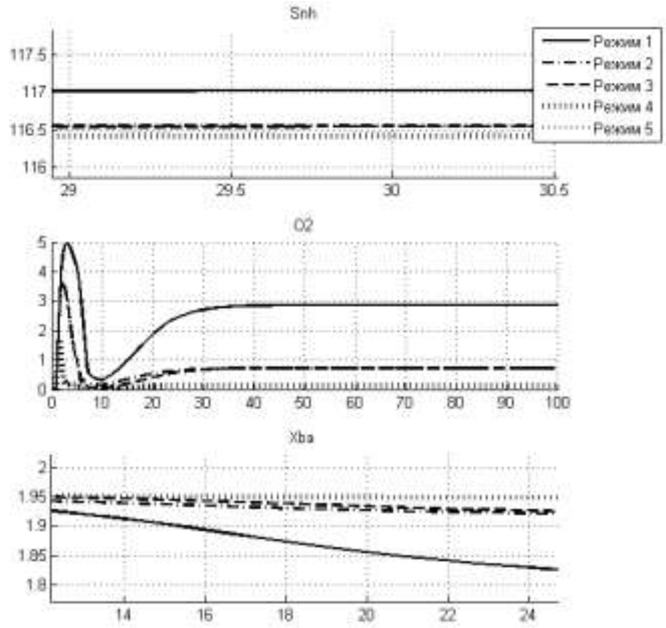

Fig. 2. Schedules of results of model operation of temperature effect on concentration of ammoniyny nitrogen, bacteria nitrifiers and oxygen.

Process control of a nitrification is in turn exercised by means of oxygen supply. However this research also showed dependence of population of bacteria nitrifiers on temperature.

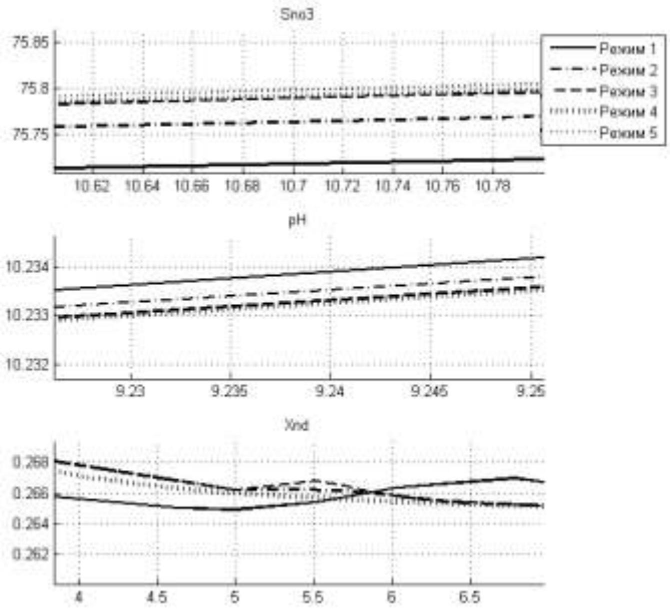

Fig. 3. Schedules of results of model operation of temperature effect on a causeticity, concentration of the fluidized organic sluggish decomposed nitrogen, concentration of nitric nitrogen

III. Denitrification model taking into account the temperature factor

The denitrification is a microbiological process of transformation of nitrate into atmospheric nitrogen as a result of effect of bacteria. Process proceeds in the conditions of lack of oxygen, and an oxidizing element is nitrate. It is accepted to call such conditions anoxic. In case of oxygen availability denitrifying bacteria mainly use it as oxidizer. By consideration of model of a denitrification it is supposed that process of a nitrification is absent in the considered volume. Also it is necessary that are present at an entrance stream only ammoniyny and nitric soluble nitrogen. As a result of detailed studying of process of a denitrification the conceptual model in the form of the scheme (Fig. 4) is received.

Fig. 4. Conceptual process flow diagram of a denitrifkation

This scheme, as well as the scheme of model of a nitrification, allows to trace the main reactions of this process and interference of separate components at each other. Shooters on the scheme carry the same sense, as for conceptual model of a nitrification.

The denitrifications of the name of sizes accepted for model and also their designation and unit of measure are reduced in table 3. According to the provided conceptual scheme MM of processes of the bioreactor denitrifier taking into account temperature effect registers as follows:

$$\frac{dX_{ba}}{dt} = -\frac{dX_{ba}}{T} + (\mu_{bh}^{20°C}\exp^{\gamma(\theta-20)}\eta_g \frac{S_s}{S_s+K_s}\frac{K_{oh}}{S_o+K_{oh}}\frac{S_{no}}{S_{no}+K_{no}} - b_h)\,X_{bh};$$

$$\frac{dS_{nh}}{dt} = \frac{S_{nh}^{\text{вх}} - S_{nh}}{T} + (-i_{xi}\mu_{bh}^{20°C}\exp^{\gamma(\theta-20)}\eta_g \frac{S_s}{S_s+K_s}\frac{K_{oh}}{S_o+K_{oh}} \frac{S_{no}}{S_{no}+K_{no}} + k_a S_{nd})X_{bh};$$

$$\frac{dS_{no}}{dt} = \frac{S_{no}^{\text{вх}} - S_{no}}{T} - \frac{1-Y_h}{2{,}86Y_h}\mu_{bh}^{20°C}\exp^{\gamma(\theta-20)}\eta_g \frac{S_s}{S_s+K_s}\frac{K_{oh}}{S_o+K_{oh}} \frac{S_{no}}{S_{no}+K_{no}} X_{bh};$$

$$\frac{dS_s}{dt} = \frac{S_s^{\text{вх}} - S_s}{T} - \frac{1}{Y_h}\mu_{bh}^{20°C}\exp^{\gamma(\theta-20)}\eta_g \frac{S_s}{S_s+K_s}\frac{K_{oh}}{S_o+K_{oh}}\frac{S_{no}}{S_{no}+K_{no}} X_{bh} + k_h X_s;$$

$$\frac{dX_s}{dt} = -\frac{X_s}{T} + (1-i_{xi})b_h X_{bh} - k_h X_s;$$

$$\frac{dX_{nd}}{dt} = -\frac{X_{nd}}{T} + i_{xb} b_h X_{bh} - k_h X_{nd};$$

$$\frac{dS_{nd}}{dt} = -\frac{S_{nd}}{T} + k_h X_{nd} - k_a S_{nd} X_{bh};$$

$$\frac{dS_{alk}}{dt} = \frac{S_{alk}^{\text{вх}} - S_{alk}}{T} + \left(\frac{1-Y_h}{14\cdot 2{,}86Y_h} - \frac{i_{xb}}{14}\right)\mu_{bh}^{20°C}\exp^{\gamma(\theta-20)}\eta_g \frac{S_s}{S_s+K_s} \frac{K_{oh}}{S_o+K_{oh}}\frac{S_{no}}{S_{no}+K_{no}} X_{bh} + \frac{1}{14}k_a S_{nd} X_{bh};$$

$$\frac{dX_i}{dt} = -\frac{X_i}{T} + i_{xi} b_h X_{bh}.$$

TABLE III. NAME, DESIGNATIONS AND UNITS OF MEASURE AND PARAMETERS FOR THE DENITRIFKATION MODEL

Name of sizes and parameters	Designation	Unit of measure
Concentration of biomass of geterotrof	X_{bh}	g ХПК/m3
Concentration of the dissolved organic nitrogen	S_{nd}	g N/m3
Concentration of the suspended organic sluggishly decomposed matter	X_s	g ХПК/m3
Concentration of the suspended organic sluggishly decomposed matter	S_s	g ХПК/m3
Concentration of suspended inert organic matter	X_i	g ХПК/m3
Saturation constant on oxygen for geterotrof	K_{oh}	g O2/m3
Semi-saturation constant on an ammonium at a nitrification	K_{nh}	g NH4+/m3
Semi-saturation constant on easily decomposable organic substratum at a denitrification	K_s	g ХПК/m3
Semi-saturation constant on nitrate at a denitrification	K_{no}	g NO3-/m3

Name of sizes and parameters	Designation	Unit of measure
Fraction of nitrogen in biomass of the fissile ooze	i_{xb}	gN/g ХПК
Fraction of nitrogen in the mass of products of disintegration	i_{xi}	gN/g ХПК
The correcting factor of growth rate of geterotrof in anoksidny conditions	η_g	-
Constant of disintegration of denitrifying bacteria	b_h	day^{-1}
The maximal coefficient of an increase of biomass for geterotrofny bacteria	Y_h	g ХПК/gN
Hydrolysis constant in reaction of first order	k_h	day^{-1}
Ammonification speed	k_a	$gNH4^-/(gNday^{-1})$
The maximal specific growth rate of autotrophs at 20 °C	$\mu_{bh}^{20°C}$	day^{-1}
Temperature coefficient	γ	-
Ambient temperature	θ	°C

Results of computer model operation of model of a denitrification taking into account a temperature factor are presented in the form of schedules according to the figure 5.

From schedules it is visible that the temperature schedule 5, answers the greatest changes in process of a denitrification. All other temperature schedules lead to similar changes. Temperature increase up to 40 °C leads to an increase of number of bacteria-nitrifaktorov, and further decrease in temperature to tentative value reduce their concentration to value equal at 20 °C.

Increase in temperature up to 40 °C reduces concentration of nitrates and an ammonium, increasing a causeticity to decrease of concentration of nitrates and an ammonium and Wednesday. Body height of bacteria denitrifiers brings to increase in concentration of nitrogen. Increase in temperature, and up to 40 °C promoted weakening of the dissolved biologically decomposed substance. In this regard, it is possible to draw a conclusion that process of a denitrification needs to be considered in more detail in the conditions of elevated temperature of the environment.

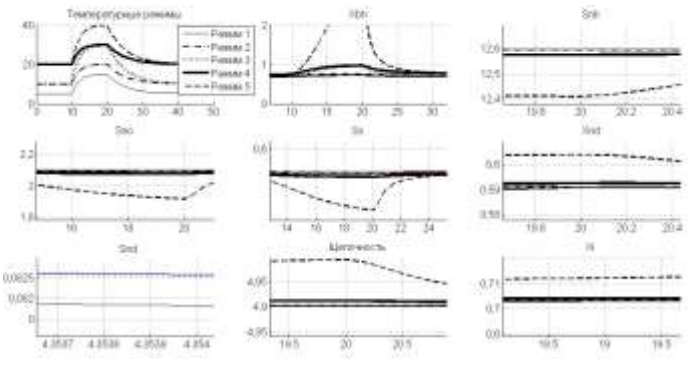

Fig. 5. Results of computer model operation of process of a denitrification taking into account parmetr of the external environment.

IV. CONCLUSION

Mathematical and computer models of a nitrification and denitrification taking into account temperature effect on the growth rate of biological process are result of this research. One of the main results of this research is confirmation of sensitivity of processes of a nitrification and denitrification to environment temperature. Temperature schedules at which the best indicators of body height of bacteria nitrifiers and denitrifiers are reached are defined.

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