Computer modeling of water purification in bioplateau taking into account biodegradation processes and greenhouse gas emissions

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***Abstrac* – The authors' research concerns the equations of filtration of contaminated water with dispersed particles of organic residues. A review of works, formulation of research tasks and a mathematical model of filtration with consideration of clogging and suffusion processes and biodegradation are carried out. Dependencies for estimating the volume of greenhouse gases released as a result of biodegradation of organic pollution are proposed (Abstract)**

***Keywords* – filtration; bioplateau; biodegradation; emission; greenhouse gases (key words)**

I. Introduction

Bioplateau is one of the energy-saving methods of water treatment [1]. Let's assume that contaminated water enters the bioplateau along with dispersed particles of organic residues. As a result, they (the particles) clog the pore space of the filter bed, but also undergo biodegradation processes [2, 3]. Biodegradation results in the generation of greenhouse gases (mainly carbon dioxide and methane) [4] and their emission into the atmosphere. Greenhouse gas emissions also occur during the formation of humus [5], as a result of the transformation of organic residues in the soil.

Works [6, 7] investigated the processes of water purification under conditions of variable backfill porosity using mathematical and computer modeling methods. In particular, it is shown that clogging, when taken into account in predictive models, can reduce the efficiency and productivity of the bioplateau by 25% during the year. However, the biodegradation processes in case of contamination with organic particles were not taken into account. This is the purpose and novelty of this research.

II. Mathematical Model of Filtration with Consideration of Clogging-Suffosion and Biodegradation Processes

Thus, the mathematical model of filtration, taking into account clogging and suffusion processes and biodegradation processes, will contain the following equations:

$$\nabla \cdot \left(\rho_p(c) k_h(c,s,\sigma) \nabla h\right) = \sigma \frac{\partial \rho_p}{\partial c} \cdot \frac{\partial c}{\partial t} - \frac{\rho_p}{\rho_s} \frac{\partial s}{\partial t}, \mathrm{X} \in \Omega, \quad (1)$$

$$\sigma\left(1 - \frac{c}{\rho_p}\frac{\partial \rho_p}{\partial c}\right)\frac{\partial c}{\partial t} = \nabla \cdot (D_c \nabla c) -$$
$$-\left(u\left(1 - \frac{c}{\rho_p}\frac{\partial \rho_p}{\partial c}\right) - w\right)\nabla c - \frac{\partial s}{\partial t}, \mathrm{X} \in \Omega, \quad (2)$$

$$\frac{\partial s}{\partial t} = \alpha \cdot c - \beta \cdot s - k_f s(X,t), \mathrm{X} \in \Omega, \quad (3)$$

$$u = -k_h(c,s,\sigma)\nabla h, \mathrm{X} \in \Omega, \quad (4)$$

Here $\sigma(X,t) = \sigma_0(X) - \frac{s(X,t)}{\rho_s}$ is the backfill porosity, which is variable in time due to changes in the concentration of clogging particles; $\sigma_0(X)$ is the porosity of the backfill "skeleton" in the complete absence of clogging particles; $s(X,t)$ is the mass concentration of clogging particles (mass of particles associated with the backfill skeleton and referred to a unit volume of the porous medium); c is the concentration of the suspension to be filtered (mass of suspended particles per unit volume of pore fluid); ρ_s is the density of the clogging particles; $k_h=k_h(c,s,\sigma)$ is the filtration coefficient, which depends on the suspension concentration and porosity; h is the pressure in the pore fluid; D_c is the coefficient of particle dispersion in the pore suspension; $u=-k_h(c,s,\sigma)div\ h$ is the filtration rate of the pore suspension; w is the settling rate of solid particles of the suspension; α is the coefficient of particle adhesion rate; β is the coefficient of particle detachment rate; k_f is the coefficient of biodegradation of organic particles.

The third term «$-k_f s(X,t)$» in the right side (3) represents biodegradation processes according to the simplest biodegradation model [1]

$$s(X,t) = s^{(0)}\exp\left(-k_f t\right).$$

Then we have

$$\frac{\partial s(X,t)}{\partial t} = -k_f s^{(0)}\exp\left(-k_f t\right)$$

or

$$\frac{\partial s(X,t)}{\partial t} = -k_f s(X,t). \quad (5)$$

The intensity of greenhouse gas emissions, according to [8], is determined from the following dependence

$$\frac{\partial V(X,t)}{\partial t} = k_f s(X,t) L_0 \exp\left(-k_f t\right).$$

Here $V(X,t)$ is the volume of methane released per unit volume of porous backfill medium, L_0 is the total methane generation potential. Then, taking into account (5), we have

$$\frac{\partial V(X,t)}{\partial t} = -\frac{\partial s(X,t)}{\partial t} L_0 \exp\left(-k_f t\right).$$

The above formula pertains to $X \in \Omega$ If we consider $G(t)$ as the total volume of methane emitted over time $t \geq 0$, then

$$\frac{dG(t)}{dt} = -L_0 \int_{\Omega} \frac{\partial s(X,t)}{\partial t} \exp\left(-k_f t\right) dX.$$

III. Numerical Solution of the Problem and General Conclusions

Numerical solutions of the corresponding boundary value problem were found by the finite element method using FreeFem++ package [9]. One of the important input parameters is the biodegradation coefficient, which, for example, according to [3] for food waste

$$k_f = 0.00192\ \frac{1}{day}.$$

Numerical experiments were conducted and analyzed. The preliminary results show the influence of biodegradation processes on the change in the porosity of the filter bed and, consequently, on the performance of the bioplateau filter. Numerical experiments also show the possibility of significant greenhouse gas emissions in case of high water contamination with food dispersed waste.

Notes. In the above research, the proposal to take into account biodegradation processes in the mathematical model of water treatment in bioplateau, to determine greenhouse gas emissions, and to formulate algorithms for numerical solution belongs Shostak L. V. Ivanchuk N. V. and Shayniuk K. S. participated in the software implementation of the finite element solution of the corresponding boundary value problem. Martyniuk P. M. provided general scientific advice on the work and consultations on the preparation of the text of the abstract.

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