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Simulation of Industrial Wastewater Treatment from the Suspended Impurities into the Flooded Waste Mining Workings

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Abstract. The paper is dedicated to the mathematical model of slurry wastewater treatment and disposal in a flooded mine working. The goal of the research is to develop and analyze the mathematical model of suspended impurities flow and distribution. Impurity sedimentation model is under consideration. Due to the sediment compaction problem solution domain can be modified. The model allows making a forecast whether volley emission is possible. Numerical simulation results for "Kolchuginskaya" coal mine presented. Impurity concentration diagrams in outflow corresponding to the real full-scale data obtained. Safely operation time mine workings like a wastewater treatment facility are estimated. The carried out calculations demonstrate that the method of industrial wastewater treatment in flooded waste mine workings can be put into practice but it is very important to observe all the processes going on to avoid volley emission of accumulated impurities.

1. Introduction

Coal industrial wastewater treatment is still a key and very serious problem for Kuzbass. Slurry water composition is varied. It may contain suspended particles (coal dust, rock dust, clay particles), salts of heavy metals, phenols, ammonia, nitrates, nitrites, free sulfuric acid, sulfur and other hazardous substances. Their emissions into water objects can cause changes of their irreversible environmental impact. That's why wastewater should be treated or disposed.

Currently, treatment facilities of the coal enterprises, along with the traditional wastewater treatment [1–4] technology implemented another approach - requires treatment process with the help of flooded waste mining workings [5]. Natural purification of wastewater is supposed to take place in mine workings due to the water precipitation and mixture with influent underground water. This method is applied to purify slurry water of "Komsomolec" coal preparation plant in the waste mine workings of "Kolchuginskaya" coal mine.

This alternative approach is of great concern. Although, the method is quite simple and requires low costs it is essential to be researched and to be controlled underground treatment processes. In particular, it is important to avoid a volley emission when the pollution in the pumped fluid can increase greatly and significantly. Flooded mine workings can be defined to be a black box, that's why mathematical simulation and numerical experiments is the most convenient to investigation treatment processes.

At present most of papers devoted to model of the spread of suspended impurities, related to the study sediment processes [6], the formation of sediment in reservoirs or at the seaside [7–8], spreading and transport oil slicks [9–10].

There are no models allows to define how features of the sludge treatment from suspended impurities, deposition of sediments and fluid flow can affect on wastewater treatment quality in flooded mine workings and to estimate safely operation time mine workings like a wastewater treatment facility. In this paper, the suggested mathematical model considered all this factors. Mathematical and numerical simulation of wastewater treatment of dissolved impurities is described in [5].

The goal of the research is to develop and analyze the mathematical model of suspended impurities flow and distribution, and to estimate safely operation time mine workings like a wastewater treatment facility.

2. Experimental

We shall examine the solution domain G with boundary ∂G that represents flooded mine working form [5]. We consider fluid to be uniform, viscous and incompressible. Nondimentional Navier–Stokes equations system describes this fluid flow by variables “flow function-vortex”

$$\frac{\partial\omega}{\partial t}+u\frac{\partial\omega}{\partial x}+\upsilon\frac{\partial\omega}{\partial y}=\frac{1}{\mathrm{Re}}\Delta\omega;$$

$$\frac{\partial^2\psi}{\partial x^2}+\frac{\partial^2\psi}{\partial y^2}=-\omega.$$

with certain initial conditions

$$u|_{t=0}=0,\quad \upsilon|_{t=0}=0,\quad \omega|_{t=0}=0,\quad \psi|_{t=0}=0;$$

and boundary conditions

$$U=U_1(t,x,y);\quad \omega|_{\partial G}=\left(\frac{\partial\upsilon}{\partial x}-\frac{\partial u}{\partial y}\right)_{\partial G};\quad \psi|_{\partial G}=\psi_1(t,x,y),$$

where $\vec{U}=(u(t,x,y),\upsilon(t,x,y))$ – velocity vector, defined by its components u,υ; ω – vortex, ψ – flow function; $U_1(t,x,y)$, $\psi_1(t,x,y)$ – known functions, estimated on the solution domain boundary ∂G; Re – Reynold’s number.

To simulate distribution of impurities transfer equation is

$$\frac{\partial C}{\partial t}+u\frac{\partial C}{\partial x}+(\upsilon-\upsilon_S)\frac{\partial C}{\partial y}=D\left(\frac{\partial^2 C}{\partial x^2}+\frac{\partial^2 C}{\partial y^2}\right)$$

with certain initial $C(x,y,0)=C_0(x,y)$ and boundary conditions. The concentration in the enter fluid flow $C_1(x,y)$ and on the entire upper boundary $C_2(x,y)$ are known and constant, the condition of this type $\frac{\partial C}{\partial x}=0$ are put on the outlet boundary, and on the lower boundary we put boundary condition $\frac{\partial C}{\partial y}=\alpha C$.

Here C is concentration of impurity sedimentation, υ_s is velocity of impurity sedimentation, D is diffusion coefficient, α is the coefficient determines the intensity of sediment accumulation at the bottom.

Subsidence impurity and slumped impurity can eventually affect bottom shape. We simulate this process in the following way: if during the time interval T^* settled impurity concentration exceeds threshold value C^* near the boundary of solution domain, then this impurity is considered not to be affected by the flow and the solution domain boundary is shifted according to concentration C^* and time T^*.

3. Results and considerations

The formulated differential problems are solved by the grid method. The vorticity transfer equation and the impurity transfer equation are solved by the implicit scheme of stabilizing corrections. Poisson difference equation for flow function is solved by the minimal residual method of not full approximation with matrix parameter by applying component wise and overall optimization of iteration parameters [5].

Figure 1 shows the dynamics of impurity distribution and sedimentation when time values t = 1000 months for (1) impurity “heavy fraction”, (2) impurity “light fraction”, (3) total fractions.

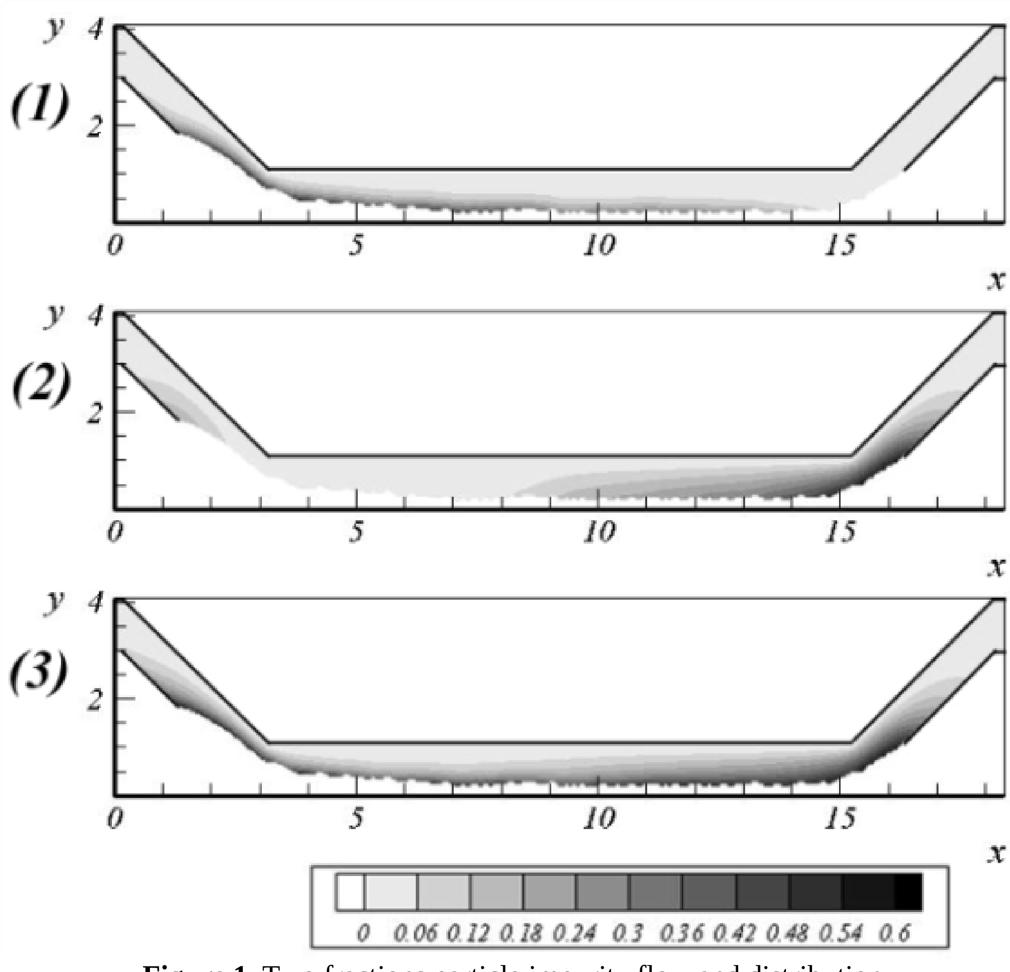

Figure 1. Two fractions particle impurity flow and distribution.

Impurity “heavy fraction” is determined with the following parameters’ values $C_1 = 0.025$; $C_2 = 0$; $D = 1$; $\upsilon_S = 2.5$; $\alpha = -5$; $C^* = 0.6$; $T^* = 1$. Impurity “light fraction” parameters are $C_1 = 0.025$; $C_2 = 0.00003$; $D = 4$; $\upsilon_S = 0.1$; $\alpha = -1$; $C^* = 0.9$; $T^* = 10$. The results for two fractions particle impurity from the "heavy" and "light" fractions are presented in (Figure 1). All nondimentionall parameters values correspond to the full-scale data obtained for the “Kolchuginskaya” coal mine [5].

Particles of "heavy" fractions are large enough to be quickly deposited and compacted sediment, it is almost not diffusion affected. Having these particles determine the intensity of the compacted sediments mine waste filling. The "light" fraction availability affects the turbidity of wastewater and has a significant impact on the outflow impurity concentration, which is shown in diagram (Figure 2).

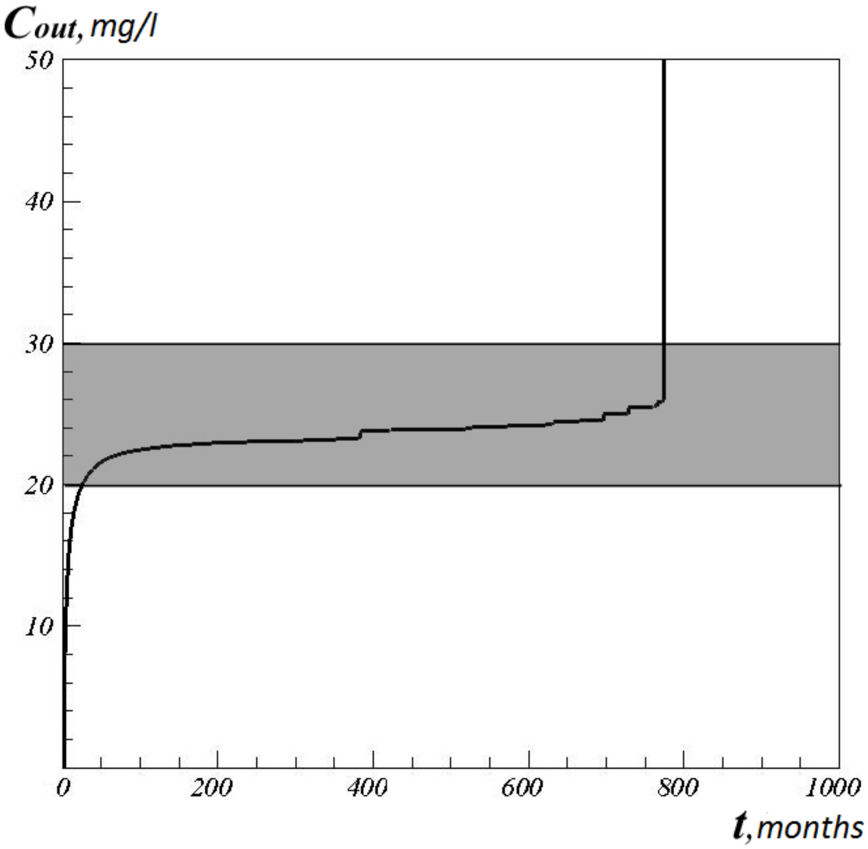

Figure 2. Diagram of impurity quantity change leaving the solution domain. A range of values corresponding to the full-scale data obtained for the “Kolchuginskaya” coal mine grayed.

Because of, these data are consistent with “Kolchuginskaya” coal mine full-scale data we can conclude that the waste water disposal process will be "safe" for approximately 60 years while maintaining constant treatment conditions. However, after this time-out, waste mine workings can be filled significantly by compacted sediment. This can lead to impurity volley emission, when the impurity concentration in outflow substantially increases.

4. Summary

The mathematical model of suspended impurity flow, distribution and settling enables to change solution domain due to the deposition of sediments in flooded mine workings suggested in this paper. Numerical simulation results for “Kolchuginskaya” coal mine presented. Impurity concentration diagrams in outflow corresponding to the real full-scale data obtained. In more details, model and obtained using it numerical simulation results is described in [11].

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