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MATHEMATICAL SIMULATION OF CONTAMINANT FLOW IN THE SQUARE CLOSED RESERVOIR

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ABSTRACT: A mathematical model of the propagation in flooded mine lightweight contaminant due to allocation of groundwater is considered. Mathematical model was based on an analysis of experimental data and using concept and methods from reactive media mechanics. The boundary-value problem is solved numerically using the finite volume method. The distribution of fields of velocities and concentration of impurity particles in a flooded mine have been obtained at different times. These results can be used to analyze mining water treatment process due to environment and evaluate its further possible improvements.

Keywords: Coal Mine, Mining Water, Water Pollution, Mathematical Model, Finite Volume.

1. INTRODUCTION

Water body pollution by mining and quarry waters is a typical problem for Kuzbass (Kuznetzk coal basin, Kemerovo Region, Russia) and many other mining regions [1]. Mining waters usually contain particles of coal dust, clay, calcium compounds, magnesium, oil products, etc. Light substances (which density is less than water density) such as oil products accumulate on water surface while other particles remain suspended or sediment gradually. The problem of mining water treatment by pumping into abandoned mines and further use of it after precipitation of impurities (for heavy particles) or impurity floating up (for light particles) is of great interest. This methodology was presented in [2]. The model in this paper is based on laminar flow. In fact, estimates indicate that for a considered area is turbulent [3]. The model which is being reported here is complex, and includes particles. The paper considers fluid flow containing impurity particles in a flooded mine.

2. PHYSICAL AND MATHEMATICAL SETTING

To analyse float impurities distribution a square form mine is under consideration. It has a ledge at the top (shown in Figure 1). Here the model of an abandoned flooded mine (Figure 1) with a drilled hole (ABCD) and the collapse of the roof, which naturally formed sump (EFGI). It is assumed that along the top of the roof was accumulated admixture (IKML, EFSR and GNOP). Across borders (KD, CI, GN) into the mine received ground water, thereby diluting the accumulated impurity. The liquid flows through the boundary AB. Some impurities imposed over from the mine, and the part retained inside the mine.

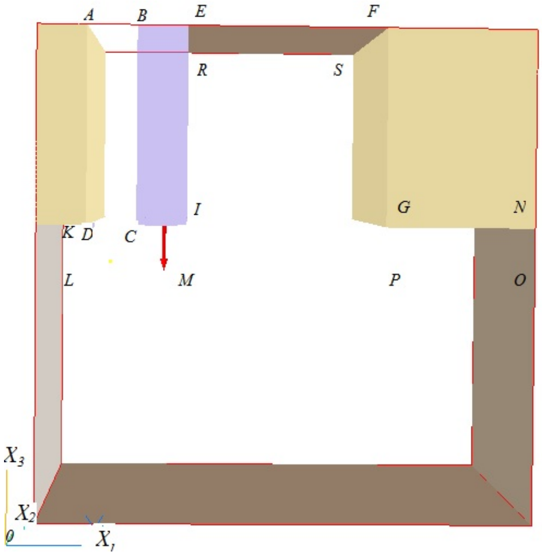


Fig. 1. Computational domain scheme.

To describe this transfer process differential equation system is used. They express the laws of conservation of mass, momentum and elements concentration in the domain. Mathematically the following differential equation system for turbulent flow should be solved. Many practical problems are devoted to such impurity distribution in an enclosed water body.

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_j}(\rho u_j) = 0 , \quad (1)$$

$$\frac{\partial}{\partial t}(\rho u_i) + \frac{\partial}{\partial x_j}(\rho u_i u_j) = -\frac{\partial p}{\partial x_i} + \quad (2)$$
$$+ \frac{\partial}{\partial x_j}(-\rho \overline{u_i' u_j'}) - \rho S C_d u_i |\vec{u}| - \rho g_i ,$$

$$\rho(\frac{\partial Y_k}{\partial t} + u_1 \frac{\partial Y_k}{\partial x_1} + (u_3 - u_{3k})\frac{\partial Y_k}{\partial x_3}) = \\ = \frac{\partial}{\partial x_j}(-\overline{\rho Y_k' u_j'}), \quad (3)$$

$$p = \rho R_0 T \sum_k \frac{Y_k}{M_k}, \quad (4)$$

$$\vec{g} = (0, g), u_{3k} = \frac{g d_k^{\ 2}}{18\nu}(\frac{\rho_k}{\rho} - 1). \quad (5)$$

The following symbols are used in the equation system above: t, x_i – time and spatial coordinates ($i,j=1,\ 3$); u_i – velocity vector projection on the corresponding axis of Cartesian reference system, p – pressure; T – temperature; g – gravitational acceleration, R_0 – absolute gas constant, M_k – molecular weight k – components, ρ – density of the mixture of fluid with particles, ν – kinematic viscosity coefficient, D_t – diffusion coefficient, d_k, ρ_k, u_{3k} - diameter, density and velocity of particle settling, Y_k – mass concentrations k – components ($k=1$ – water, 2 – solid particles). Equation system (1)-(4) contains elements related to turbulent convection and needs a closing equation. Tensor components of turbulent stresses - $\overline{\rho u_i' u_j'}$ are described with the help of mean floatation gradients according to the formulas:

$$-\rho\overline{u_i' u_j'} = \mu_t\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right) - \frac{2}{3}k\delta_{ij} \quad (6)$$

Taking into account that the flow is turbulent, the coefficient of turbulent viscosity is used $\mu_t = \rho C_\mu k^2 / \varepsilon$, where: $k = \overline{u_i'}\overline{u_i'}/2$ – turbulent kinetic energy; ε – its dissipation, C_μ- constant. The flow $-\rho\,\overline{u_i'}\overline{Y_k'}$ is modeled with the help of assumption concerning gradient diffusion $-\overline{\rho u_i' Y_k'} = \Gamma_k \frac{\partial Y_k}{\partial x_i}$,

where Γ_k – coefficient of turbulent transport, corresponding to scalar function Y_k. At this point the assumption concerning the all-around isotropic turbulence is implicitly mentioned. Transfer coefficient Γ_k for scalar functions is considered to be equal to ratio of turbulent viscosity to turbulent Prandtl number $\Gamma_k = \nu_t / \Pr_t$. The equation for turbulent kinetic energy k is as follows [3]:

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_i}(u_i \rho k) = \frac{\partial}{\partial x_i}\left[\left(\frac{\mu_t}{\sigma_k} + \mu\right)\frac{\partial k}{\partial x_i}\right] - \\ -\mu_t\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial u_j}\right)\frac{\partial u_i}{\partial x_j} - \beta\rho g_i \frac{\mu_t}{\Pr}\frac{\partial T}{\partial x_i} - \rho\varepsilon, \quad (7)$$

where $\beta = -\frac{1}{\overline{\rho}}\left(\frac{\partial\overline{\rho}}{\partial\overline{T}}\right)_p$.

The equation for dissipation of turbulent kinetic energy ε is as follows:

$$\frac{\partial}{\partial t}(\rho\varepsilon) + \frac{\partial}{\partial x_i}(u_i\rho\varepsilon) = \frac{\partial}{\partial x_i}\left[\left(\frac{\mu_t}{\sigma_\varepsilon} + \mu\right)\frac{\partial\varepsilon}{\partial x_i}\right] + \\ + C_1\frac{\varepsilon}{k}(G_k + G_B) - C_2\rho\frac{\varepsilon^2}{k}, \quad \mathbf{(8)}$$

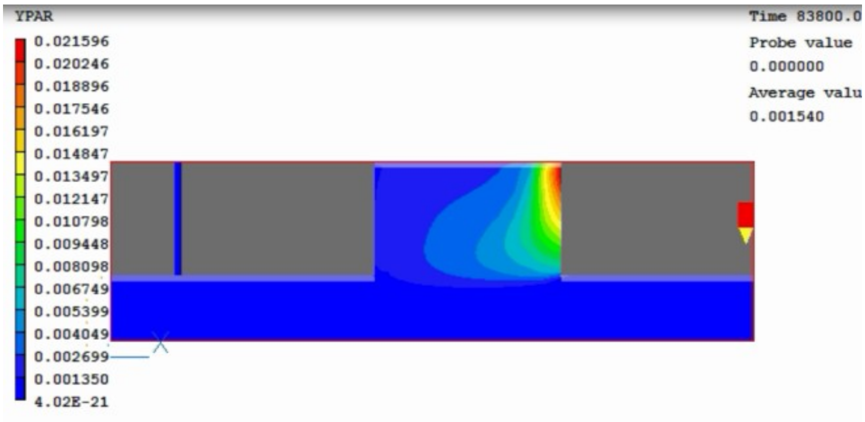
where σ_k, σ_ε, C_1, C_2 – empirical constants, and G_k, G_B – turbulence generation because of forced and natural convection.

3. NUMERICAL SOLUTION AND RESULTS

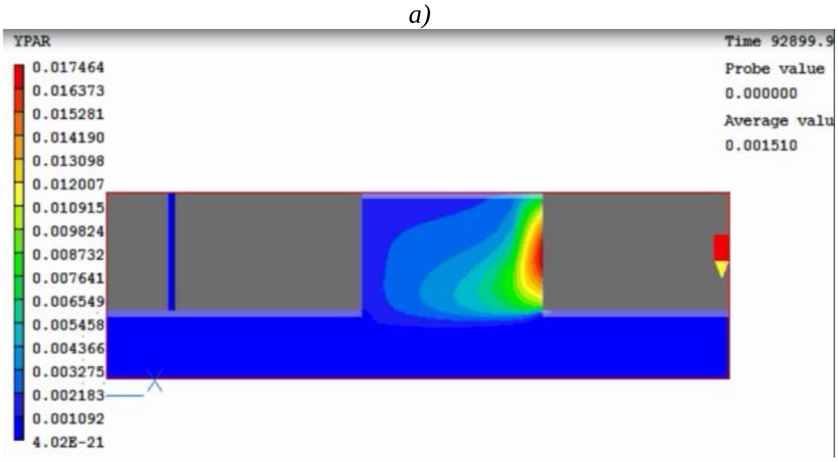
Based on mathematical formulation of the problems (1) – (8) numerical calculations were made to determine the pattern of float impurity distribution process in a flooded mine with the help of **PHOENICS** [3].

Vector fields of velocity and impurity distribution at different time moments were obtained as the result of numerical integration of equation system (1) - (8). Side walls are considered not to influence the impurity distribution process and fluid flow. Thus the problem is solved in the two-dimensional domain X_1OX_3. A mine (length – 10 meters horizontally, height-3 meters) is under consideration (Figure 1.). Underground water without any impurity enters the domain. Impurity concentration equals 1 inside the domain. Particles size is $d_k= 5\cdot10^{-5}$ m. Impurity particles density is 500 kgs/m^3 that is two times less than water density. The velocity of groundwater inflow from the upper layers is 0.1 m/s. Figure 2 shows the distribution of impurity concentration at different time moments. Figure 2 shows, that as time goes some part of the impurities transferred by a flow leaves a mine, while the remaining part is moved to a dirt collector by a vortex. In case impurity particles density is halved (as little as 250 kgs/m^3) the distributions of impurity are numerically calculated at different time moments Figures 3–5). These figures show that the flow becomes stable and impurities accumulate in the upper part of the domain as time goes. It happens faster compared with the previous case because the particles density is two times less.

Also it was carried out numerical calculation the distribution of impurity in domain when the sizes of particles were $d_k=8\cdot10^{-5}$ m (ρ_k=500 kgs/m^3 and the velocity of groundwater inflow from the upper layers is 0.1 m/s). It should be noted that in this case the flow becomes stable and impurity accumulate in the upper part faster than in previous cases (Figure 2-5). It has already happened after 300 seconds.



a)



b)

Fig.2. Impurity distribution: *a) t*=83800 sec, *b)* t=92899 sec.

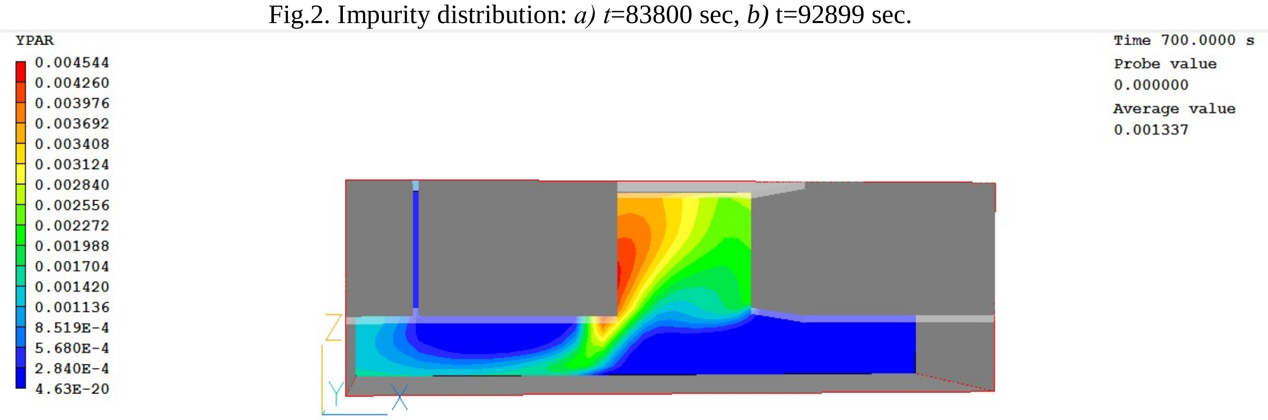


Fig.3. Distribution of impurity which density is 250 kgs/m^3 (*t*=700 sec).

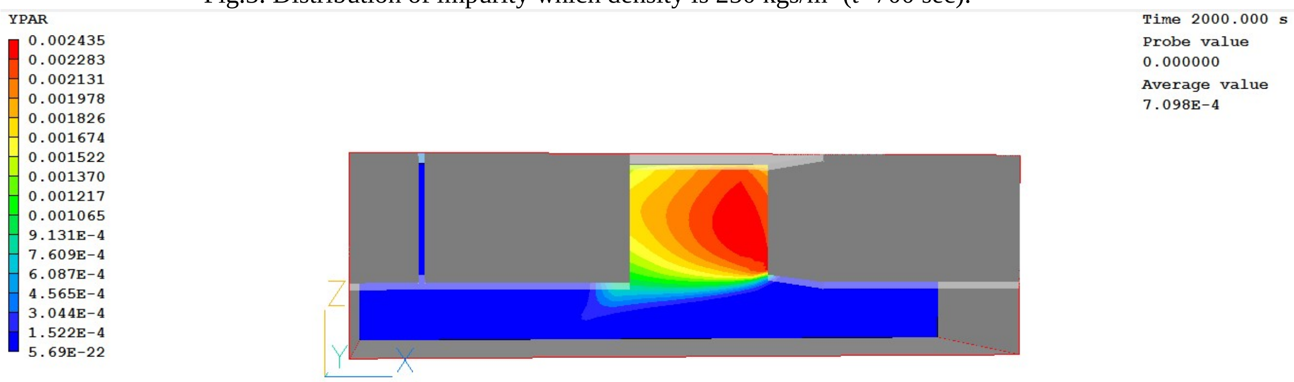


Fig.4. Distribution of impurity which density is 250 kgs/m^3 (*t*=2000 sec).

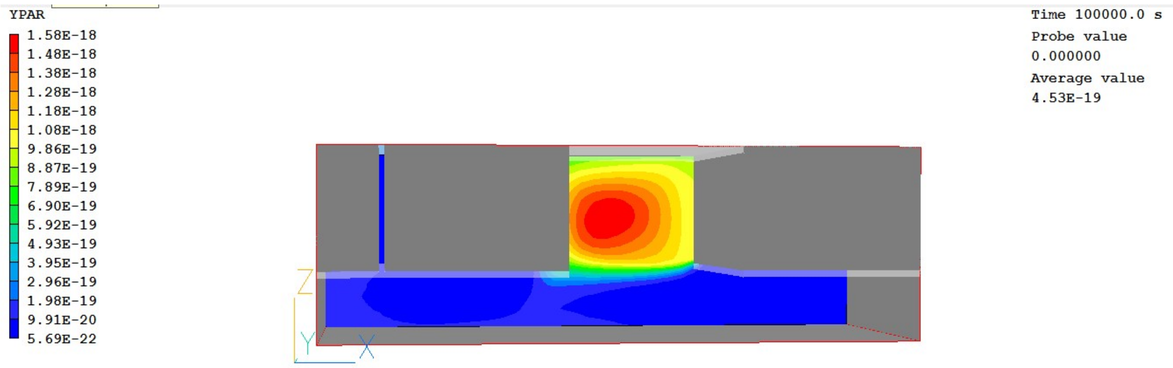


Fig.5. Distribution of impurity which density is 250 kgs/m^3 (t=10000 sec).

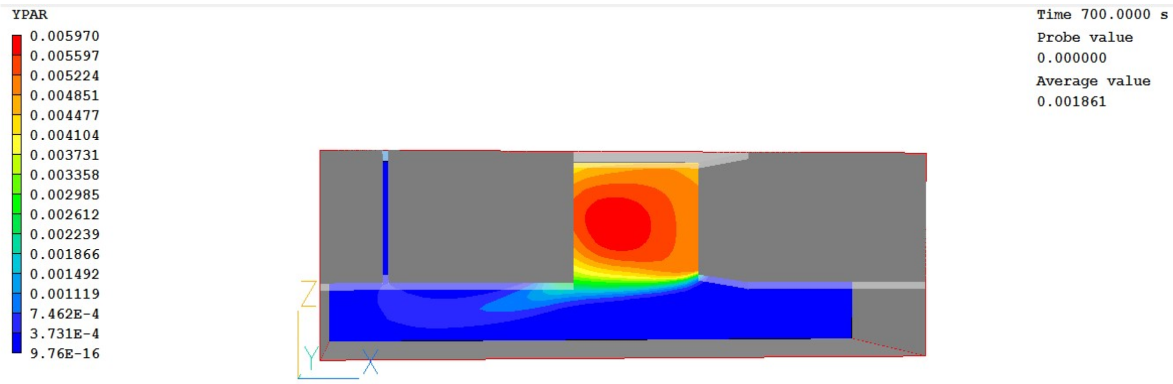


Fig. 6. Impurity distribution (t=700 sec).

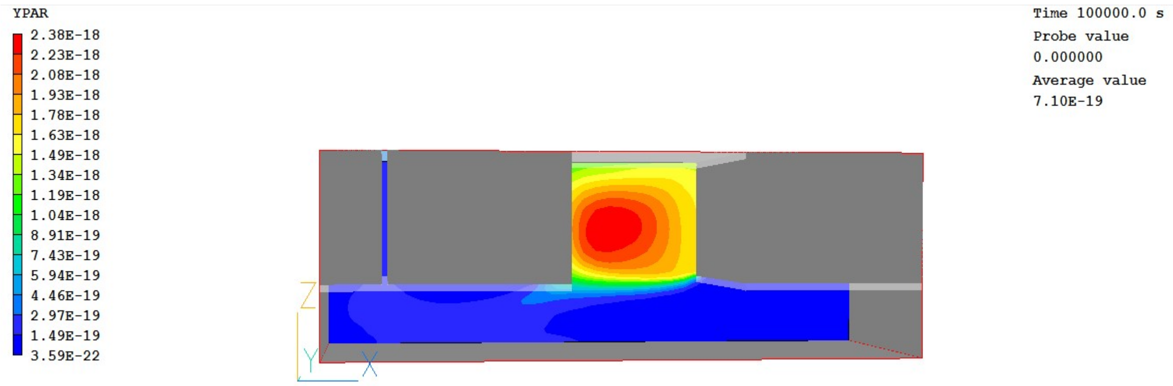


Fig. 7. Impurity distribution in a flooded mine (t=10000 sec).

Later the inflow velocity was halved as compared with the previous case (0.05 m/s). When compare the results of impurity distribution (Figures 6, 7) with the previous case at the same moment of time Figures 4, 5 correspondingly) it is obvious that the flow becomes stable and impurity concentration increases faster in the upper part of the domain.

4. CONCLUSION

Thus the results of simulation show that flow settling time depends on size and density of impurity particles and speed of receipt of groundwater in the flooded mine. The mathematical model presented in this paper can be used to analyze mining water treatment process due to environment and evaluate its further possible improvements.

The research is based on the state task № 2014/64, the state project "Scientific researches organization". The results of the numerical calculations and problem formulation will be used by the educational resources information portal that offers students, postgraduate student and academic researches different educational services.

5. REFERENCES

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