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MATHEMATICAL MODEL FOR EXPRESS EVALUATION OF PROCESS OF DUST AIR POLLUTION IN TAILING FACILITY

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Abstract. Large areas of land are allocated to the tailings of mining and processing plants. They become sources of intense dust formation after the release of the tail pulp and rapid drying due to the slope height of more than 40 m and high wind flow speeds at these heights. The development of mining and processing plants is impossible without the implementation of ecologically oriented approaches to the management of production and technologies, which involves reducing the intensity of air pollution, the underlying surface. The assessment of the pollution zone is one of the global problems of tailings, since it requires taking into account both physical and natural factors. In this research, a numerical model was developed for the rapid assessment of dust pollution in the air during the removal of dust from the tailings. The numerical model is based on solving the equation of hydrodynamics and the equation of mass transfer by finite difference methods. The Laplace equation is used to find the potential of the air flow velocity, which makes it possible to calculate the velocity field over the entire study area. The solution of the mass transfer equation makes it possible to estimate the dust concentration field, to obtain a visual representation of the concentration in the form of isolines. The study shows that the stability of the calculation is the same when the input parameters of the problem change. The developed model takes into account the geometry of the slopes, the location of the dust source and their type (point or linear), the change in the air flow velocity with height, the presence of screens at the tops of the slopes. Pollution zones correspond to the physics of the process, namely, the formation of a clearly defined halo of pollution from a constantly operating source of pollution is observed, taking into account the influence of the aerodynamics of the air flow on the formation of pollution zones. The obtained results of study can be useful both in assessing dust pollution zones and in determining the geometry of protective equipment, namely the required height of the screens. Reducing the level of dust pollution to standard values is a necessary condition for the environmentally safe living of the population in residential areas.

Keywords: tailings storage, dust pollution, mathematical modeling, numerical experiment, pollution concentration.

1. Introduction

The sustainable development of the economy of Ukraine is not possible without effective development of the mining processing industry. The largest industrial region in Ukraine related to the mining processing industry is the Kryvyi Rih Iron-ore Basin (Kryvbas). More than 80% of iron ore raw materials are mined in this region and more than 20% of metallurgical products in the country are produced. But Kryvbas is not only the largest iron ore basin in Ukraine, it is also a region of environmental problems. The main enterprises of the mining industry are concentrated here: the five largest mining and processing plants with ten quarries over 300 m deep and 17 iron ore mining mines with a depth of 80 to 1,300 m. The iron ore deposits of Kryvbas are complex in their composition, each of them is composed of two or three types of iron ores and associated non-metallic minerals. According to various estimates, the dumps of Kryvbas contain up to 13 billion tons of overburden, and over 7 billion tons of processed waste from poor iron ores that have been accumulated during the period of operation.

Iron ore beneficiation technologies used at the Kryvbas involve the generation of processing waste, their transportation and storage in special tailings facilities, into which they are fed in the form of pulp. Nowadays, about 2.7 to 3 billion m^3 of ore beneficiation waste is accumulated in the tailings storage facilities of Dnipropetrovsk region, from which more than 2 billion m^3 is in Kryvbas. At the same time, man-made water objects are created, including tailings ponds, mine water storage ponds, etc.

Today, the area of lands disturbed by quarry works and those in need of urgent restoration is about 200,000 hectares. In Dnipropetrovsk region, 140,000 hectares have been alienated for the needs of various sectors of economy, including almost 84,000 hectares of agricultural land, where 58,000 hectares are arable land. This is almost the territory of one administrative district. On the territory of Dnipropetrovsk region, there are wastes from mining, beneficiation and processing of iron, manganese, uranium ores, coal, etc. "Industrial deserts" are forming around the city of Kryvyi Rih, which not only replace agricultural land, but also have a negative impact on the environment, polluting the air, surface and groundwater.

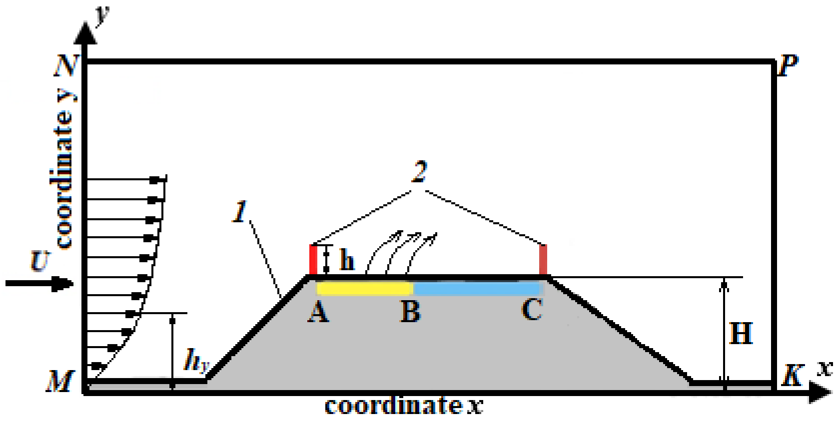
The development of mining and processing plants is impossible without the implementation of ecologically oriented approaches to the management of production and technologies, which involves reducing the intensity of air pollution, the underlying surface, based on the determination of impurity concentration fields in the area of mining and processing plants.

Analysis of recent research and publications. The theoretical solution of the problem concerned determining the intensity of air and subsurface pollution when an impurity is emitted from a specific source of pollution is based on determining the concentration of the impurity in the study area. Currently, several approaches are used to calculate the concentration field. The first is the calculation of the impurity concentration on the basis of empirical models, which make it possible to determine the impurity concentration at different distances from the source by using simplified formulas of algebraic ratios. Thus, in the research [1], an empirical model for determining the concentration of an impurity from a point source (for example, a rock dump) is considered, but to use this model, a number of empirical constants that were determined only for regions must be specified. Also, this model cannot take into account the influence of obstacles on the formation of concentration fields. Another approach is the use of analytical models. For example, works [2–3] present analytical models for determining the impurity concentration near the emission source: three-dimensional models [2] and two-dimensional models [3]. But the disadvantage of these models is also the impossibility of predicting the level of atmospheric air pollution taking into account the obstacles that may be located near the emission source and create an uneven wind profile. This drawback is also present in the Gaussian model [4], which is an analytical model that uses a number of empirical constants. CFD models are currently the most powerful models for forecasting the level of air pollution. Thus, in work [5], a CFD model is considered, which allows to predict the level of air pollution with an uneven field of air flow velocity, which is formed near an obstacle, but the use of this model requires a very powerful computers, which are not always present in project organizations, as well as the calculation time for such CFD models can be from several hours to several days. Therefore, an important problem arises in the development of CFD models, which allow taking into account the most important factors that affect the formation of impurity concentration fields, but require little time when implemented on a PC when conducting serial calculations in design and research organizations.

2. Methods

The process of removing dust from the tailings storage facility is quite complex from the point of the geometry of object, the non-stationarity of the dust removal process and the influence of meteorological parameters of air environment. Therefore, the use of analytical and empirical models to take into account all the listed components is not effective. To assess the intensity of dust pollution of the air during the emission of dust from the tailings repository, it is advisable to use the method of numerical modeling (CFD modeling). Thus, the purpose of the research is to build a CFD model for the express assessment of dust pollution of the air during the removal of dust from the tailings storage, and accordingly to expand the possibilities of conducting a large number of computational experiments for a more detailed study of this process.

Mathematical model. Forecasting the level of atmospheric air pollution during the emission of dust from a certain surface of the tailings storage is based on the solution of two problems: the problem of aerodynamics (determination of the air flow velocity field in conditions of complex terrain and the presence of various types of obstacles) and the solution of the problem of mass transfer of impurities. The construction of a mathematical model for rapid assessment of the dust pollution process of air during removal of dust from the surface of the tailings storage facility. The scheme of the *MNPK* calculation area is shown in Figure 1.



1 – tailings storage facility*; 2* – screens
Figure 1 – The scheme of the calculation area

A potential motion model is used to solve the problem of aerodynamics. The modeling equation has the form (1) [6; 8], where P is the air flow velocity potential.

$$\frac{\partial^2 P}{\partial x^2}+\frac{\partial^2 P}{\partial y^2}=0. \qquad (1)$$

Boundary conditions are set for solving the equation (Fig. 1):

– at the border of *MN*, where the air flow enters the calculation area, a condition is $\frac{\partial P}{\partial x} = U$, where U – the value of the wind speed at the height $h = y$ $U = U_1 \cdot (y / y_1)^{n_1}$, where U_1 wind speed at the level y_1 =10 m, n_1 =0,15 [1; 7].

Thus, the change in air flow speed with height is taken into account in the model h_y (Fig. 1), which makes it possible to carry out a reasonable calculation of the removal of tailings, which is located at a certain height H and if there are height h barriers on it.

– at the exit boundary of the air flow *PK* a boundary condition $P = P_0 + const$ is imposed, where P_0 – some constant;

– on all impervious boundaries, as well as on the surface of the water in the tailings (Fig.1, border *BC*) the condition $\frac{\partial P}{\partial n} = 0$ is met, n – external unit normal vector.

The components of the air flow velocity vector are determined by the ratio (2) [8]:

$$u = \frac{\partial P}{\partial x}, \; v = \frac{\partial P}{\partial y}. \tag{2}$$

The mass transfer equation is used to model the process of dust spreading from a certain area of the tailings storage (border *AB*, Fig.1) (3) [2; 8]:

$$\frac{\partial C}{\partial t} + \frac{\partial uC}{\partial x} + \frac{\partial (v - w_g)C}{\partial y} = \frac{\partial}{\partial x}\left(\mu_x \frac{\partial C}{\partial x}\right) + \frac{\partial}{\partial y}\left(\mu_y \frac{\partial C}{\partial y}\right) + \sum_{i=1}^{N} Q_i(t)\delta(x - x_i, y - y_i) \tag{3}$$

where C – dust concentration, [mg/ m^3]; u, v – components of the wind speed vector, [m/ s]; μ_x, μ_y – coefficients of atmospheric turbulent diffusion, [m^2/s]; w_g – rate of gravitational settling of dust, [m/ s]; $Q_i(t)$ – intensity of dust removal from section *AB* in the figure 1, [mg/ (s·m^3)]; $\delta(x,y)$ – Dirac delta function; (x_i, y_i) – coordinates of the dust emission source, [m]; t – time, [s].

The following boundary conditions are set for equation (3) [8]:

1. At the boundary of the air flow entry into the calculation area, the dust concentration is set to zero $C = 0$;
2. The area of dust removal on the shore of tailings storage (Fig. 1, border *AB*) is modeled by a set of point sources with a known intensity of emission $Q_i(t)$;

3. On all solid walls, depending on the direction of the normal, the impenetrability condition must be fulfilled, which requires the equality of zero changes in the concentration of normal to the surface $\frac{\partial C}{\partial n} = 0$.

4. The diffusion process is not taken into account at the exit boundary of the air flow from the calculation area $\frac{\partial C}{\partial x} = 0$.

5. At the initial moment of time, the dust concentration is assumed to be zero $C_{t=0} = 0$. If necessary, it is possible to set any other value of dust concentration, for example, determined by experimental measurements or some background value.

Numerical model. Numerical integration of modeling equations is carried out on a rectangular difference grid. First, the Laplace equation (1) is reduced to an equation of the "evolutionary" form with the application of setting the solution in time [6]:

$$\frac{\partial P}{\partial t} = \frac{\partial^2 P}{\partial x^2} + \frac{\partial^2 P}{\partial y^2}, \tag{4}$$

where t – fictitious time, at $t \to \infty$, the solution of equation (4) leads to the solution of Laplace equation (1).

Next, the equation (4) is solved using a conditionally approximating scheme [6]. The differential equations have the form:

– in the first step of splitting:

$$\frac{P_{i,j}^{n+\frac{1}{2}} - P_{i,j}^{n}}{\Delta t} = \frac{-P_{i,j}^{n+\frac{1}{2}} + P_{i-1,j}^{n+\frac{1}{2}}}{\Delta x^2} + \frac{-P_{i,j}^{n+\frac{1}{2}} + P_{i,j-1}^{n+\frac{1}{2}}}{\Delta y^2}. \tag{5}$$

– in the second step of splitting:

$$\frac{P_{i,j}^{n+1} - P_{i,j}^{n+\frac{1}{2}}}{\Delta t} = \frac{P_{i+1,j}^{n+1} - P_{i,j}^{n+1}}{\Delta x^2} + \frac{P_{i,j+1}^{n+1} + P_{i,j}^{n+1}}{\Delta y^2}. \tag{6}$$

At each splitting step, the unknown value of the velocity potential is found by an explicit formula. The calculation ends when the condition $\left|P_{i,j}^{n+1} - P_{i,j}^{n}\right| \le \varepsilon$ is met, where ε – accuracy of calculations, $\varepsilon = 10^{-3} \div 10^{-6}$, n – iteration number (number of time steps), for these calculations it was assumed that $\varepsilon = 0{,}001$.

To start the calculation, it is assumed that $P_{t=0} = 0$.

After finding the velocity potential field, the components of the air flow velocity vector are determined [8]:

$$u_{i,j} = \frac{P_{i,j} - P_{i-1,j}}{\Delta x}, \; v_{i,j} = \frac{P_{i,j} - P_{i,j-1}}{\Delta y}. \tag{7}$$

The components of the air flow velocity vector are determined on the sides of the difference cells.

At the differential level, the mass transfer modeling equation (3) is split into three components.

$$\frac{\partial C}{\partial t} + \frac{\partial uC}{\partial x} + \frac{\partial vC}{\partial y} = 0 \;, \tag{8}$$

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial x}\left(\mu_x \frac{\partial C}{\partial x}\right) + \frac{\partial}{\partial y}\left(\mu_y \frac{\partial C}{\partial y}\right), \tag{9}$$

$$\frac{\partial C}{\partial t} = \sum_{i=1}^{N} Q_i(t) \cdot \delta(x - x_i, y - y_i) \;, \tag{10}$$

where $v=v-w_g$.

In such a split, equation (8) describes the process of impurity transfer under the influence of the directed movement of the air flow. Equation (9) is transfer under the influence of diffusion, and equation (10) is the change in impurity concentration under the influence of sources.

Next, derivatives are approximated [3; 8]. The time derivative is approximated by the divided difference "backwards":

$$\frac{\partial C}{\partial t} \approx \frac{C_{ij}^{n+1} - C_{ij}^{n}}{\Delta t}.$$

In convective derivatives, the components of unidirectional transfer are written as:

$$\frac{\partial uC}{\partial x} = \frac{\partial u^{+}C}{\partial x} + \frac{\partial u^{-}C}{\partial x}; \qquad \frac{\partial vC}{\partial y} = \frac{\partial v^{+}C}{\partial y} + \frac{\partial v^{-}C}{\partial y}.$$

Taking into account the previous expression, the convective derivatives are approximated by separated differences "upstream" in the upper time layer:

$$\frac{\partial u^{+}C}{\partial x} \approx \frac{\overset{+}{u}_{i+1,j}C_{i,j}^{n+1} - \overset{+}{u}_{i,j}C_{i-1,j}^{n+1}}{\Delta x} = L_x^{+}C^{n+1},$$

$$\frac{\partial u^{-}C}{\partial x} \approx \frac{\overset{-}{u}_{i+1,j}C_{i+1,j}^{n+1} - \overset{-}{u}_{i,j}C_{i,j}^{n+1}}{\Delta x} = L_x^{-}C^{n+1},$$

$$\frac{\partial v^{+}C}{\partial y} \approx \frac{\overset{+}{v}_{i,j+1}C_{i,j}^{n+1} - \overset{+}{v}_{i,l}C_{i,j-1}^{n+1}}{\Delta y} = L_y^{+}C^{n+1},$$

$$\frac{\partial v^{-}C}{\partial y} \approx \frac{\overset{-}{v}_{i,j+1}C_{i,j+1}^{n+1} - \overset{-}{v}_{i,j}C_{i,j}^{n+1}}{\Delta y} = L_y^{-}C^{n+1}.$$

where $u^{+} = \frac{u+|u|}{2}$, $u^{-} = \frac{u-|u|}{2}$, $v^{+} = \frac{v+|v|}{2}$, $v^{-} = \frac{v-|v|}{2}$.

Next, the following splitting is performed in four steps:

– on the first step, k=1/4: $\frac{C_{i,j}^{n+k} - C_{i,j}^{n}}{\Delta t} + \frac{1}{2}(L_x^{+}C^{k} + L_y^{+}C^{k}) = 0$;

– on the second step, k=1/2, p=n+1/4: $\frac{C_{i,j}^{k} - C_{i,j}^{p}}{\Delta t} + \frac{1}{2}(L_x^{-}C^{k} + L_y^{-}C^{k}) = 0$;

– on the third step, k=n+3/4, p=n+1/2: $\frac{C_{i,j}^{k} - C_{i,j}^{p}}{\Delta t} + \frac{1}{2}(L_x^{-}C^{k} + L_y^{-}C^{k}) = 0$;

– on the fourth step, k=n+1, p=n+3/4: $\frac{C_{i,j}^{k} - C_{i,j}^{p}}{\Delta t} + \frac{1}{2}(L_x^{+}C^{k} + L_y^{+}C^{k}) = 0$.

The unknown concentration value of equation (8) is found according to an explicit scheme at each cleavage step.

For the numerical solution of equation (9), a two-step splitting scheme is used [8]:
– at the first step of splitting, the difference equation has the form:

$$\frac{C_{i,j}^{n+\frac{1}{2}} - C_{i,j}^{n}}{\Delta t} = \left[\mu_x \frac{-C_{i,j}^{n+\frac{1}{2}} + C_{i-1,j}^{n+\frac{1}{2}}}{\Delta x^2} \right] + \left[\mu_y \frac{-C_{i,j}^{n+\frac{1}{2}} + C_{i,j-1}^{n+\frac{1}{2}}}{\Delta y^2} \right], \qquad (11)$$

– at the second step of splitting, the difference equation has the form:

$$\frac{C_{i,j}^{n+1} - C_{i,j}^{n+\frac{1}{2}}}{\Delta t} = \left[\mu_x \frac{C_{i+1,j}^{n+1} - C_{i,j}^{n+1}}{\Delta x^2} \right] + \left[\mu_y \frac{C_{i,j+1}^{n+1} + C_{i,j}^{n+1}}{\Delta y^2} \right], \qquad (12)$$

The Euler method [6] is used for the numerical integration of equation (10). The calculated dependence has the form:

$$C_{i,j}^{n+1} = C_{i,j}^{n} + \Delta t \cdot \sum_{i=1}^{N} Q_i(t) \cdot \delta(x - x_i, y - y_i) \ . \qquad (13)$$

The software implementation of the developed numerical model was carried out. The «*HILL-2*» program package was been created.

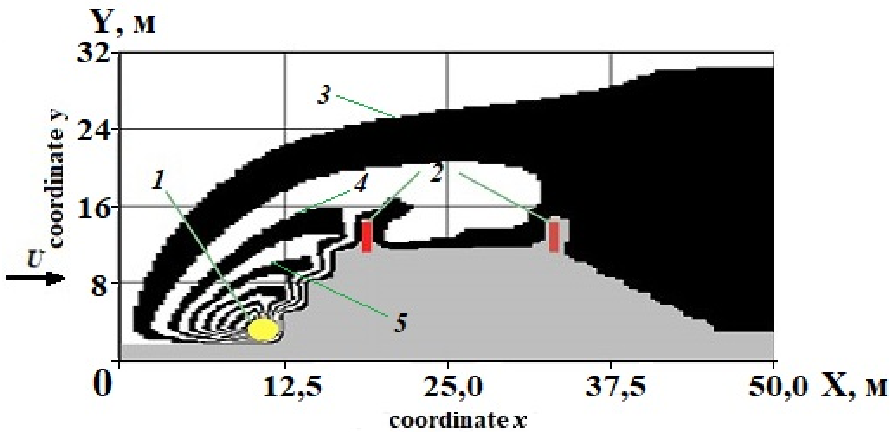
It should be noted that to determine the intensity of dust emission from a site, it makes sense to use empirical models obtained for specific operating conditions of a particular object [9]. Such models can take into account the specifics of dust (particle diameter), dust humidity, etc.

3. Results and discussion

The built numerical model was used to conduct parametric studies in order to determine its stability for the case of calculating the spread of impurities in the area of a complex geometric shape. Numerical stability is a basic requirement for numerical methods. It is known that this or that finite-difference scheme (method) can be stable from a theoretical point of view – for example, such a result was obtained when studying the stability of the model equation. However, when calculating in areas with complex boundary geometry, a loss of stability may occur. Besides, the fictitious sources or drains may appear during calculations in such areas. This makes it impossible to further solve the impurity propagation problem, because "additional sources" appear in the calculation domain, that is, we get a non-physical solution to the problem. Therefore, parametric studies are very important in order to confirm the robustness of the method.

Parametric studies were conducted as follows. Firstly, the location of the dust emission source was changed. That is, the source was located in the area with a low speed of air flow (Fig.2, scenario 1), and in the area with a fairly high speed (Fig.4, scenario 2), in addition, the intensity of dust emission of the pollution source varied. Secondly, the calculation was carried out for different internal geometries: in the presence of screens and in the absence of screens (Fig.6, scenario 3, Fig.8, scenario 4).

When conducting computer experiments, the calculation was carried out with the following data: the height of the screen on the left was 3 m, on the right is 3 m or 6 m; air flow speed *U*=5 m/ s; it was assumed that the diffusion coefficients were determined by the ratios, $\mu_x = k \cdot u(x, y)$, $\mu_y = k \cdot v(x, y)$, that is, the value of the atmospheric diffusion coefficients depends on the local value of the air flow speed. Figure 2 shows the pollution zone (isolines of dust concentration) for the first scenario, when the source of pollution is located below, in the zone of low air flow speeds, and screens of the same height *h*=3 m are located above. Figure 3 shows the distribution of dust concentration on the *AC* site, the approximating equation has the form: $y = 0.017x^2 - 1.0398x + 17.776$ ($R^2 = 0.9839$).



1 – place of dust emission; *2* – screens;
3 – *C*=2.44 mg/ m³; *4* – *C*=5.69 mg/ m³; *5* – *C*=8.94 mg/ m³

Figure 2 – Zone of dust pollution (scenario 1, dust emission intensity Q=200 mg/s)

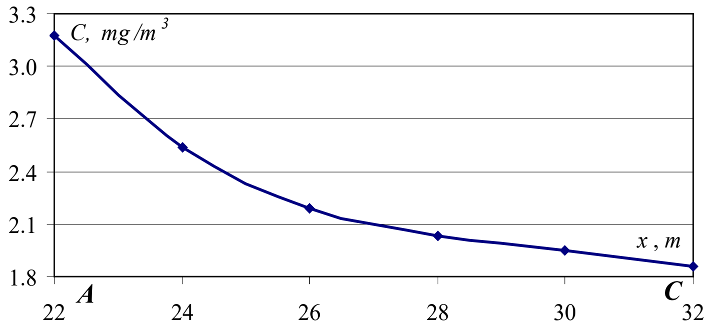
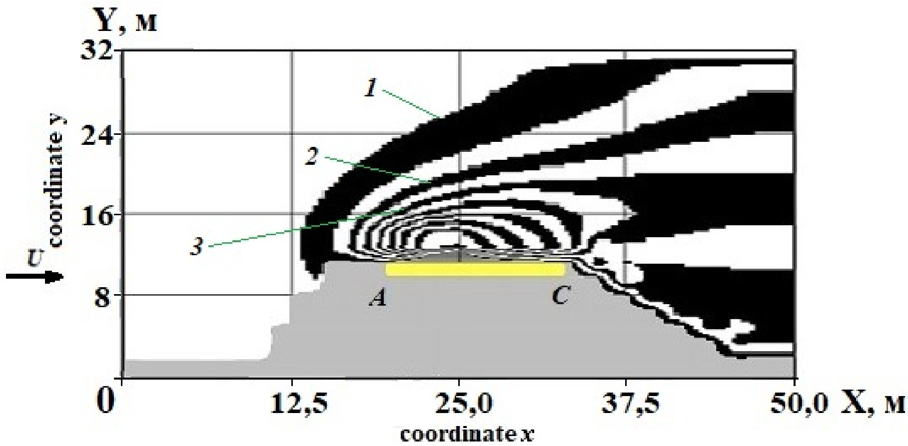


Figure 3 – Distribution of the concentration of dust pollution at the *AC* site (scenario 1)

The concentration of pollution slowly changes from the source of pollution located below (Fig. 2, position 1). A zone with a significant dust concentration gradient is formed near the source of pollution. However, since there are screens on top which prevent the movement of pollution, the most intensive area of pollution is formed on the windward side of the tailings storage facility.

Figure 4 shows the pollution zone when the source is located on top of the tailings storage, but in the absence of screens (Fig. 4 zone *AC*). Figure 5 shows the distribution of dust concentration on the *AC* site, the approximating equation has the form: $y = 0.0217x^3 - 1.939x^2 + 56.938x - 540.08$.



1 – C=1.22 mg/m^3; *2* – C=2.85 mg/m^3; *3* – C=4.48 mg/m^3

Figure 4 – Zone of dust pollution (scenario 2, intensity of dust emission from the site Q=600 mg/s)

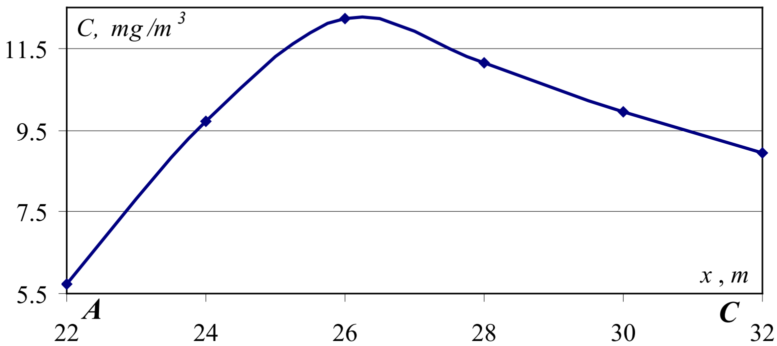
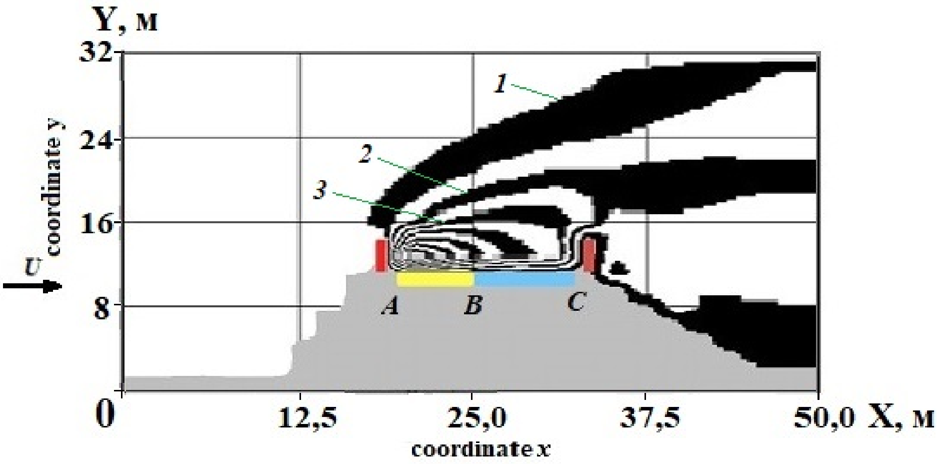


Figure 5 –Distribution of the concentration of dust pollution at the *AC* site (scenario 2)

This is a zone of fairly significant wind speeds in the absence of screens, which leads to active deflating of dust and its unimpeded movement, the level of dust concentration is significant, its reduction occurs only due to diffusion. The territory located behind the tailings storage facility in the direction of the wind is significantly affected by harmful factors, namely dust blown from the surface of the object.

Figure 6 shows the pollution zone (scenario 3), when the dust emission source has a certain length (Fig.6, zone *AB*), there is an area with water nearby (Fig. 6, zone *BC*), and there are also screens of the same height h= 3 m on both sides. Such a configuration has the appearance of an "emission source inside a cavern". Figure 7 shows the distribution of dust concentration on the *AC* site, the approximating equation has the form: $y = 0.0039x^4 - 0.4026x^3 + 15.264x^2 - 252.8x + 1557.3$.



1 – C=0.57 mg/m^3; *2* – C=2.85 mg/m^3; *3* – C=5.13 mg/m^3

Figure 6 – Zone of dust pollution (scenario 3, intensity of dust emission from the site Q=600 mg/s)

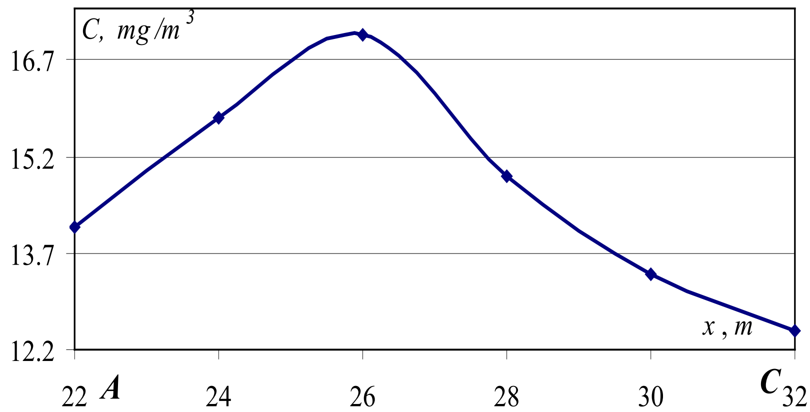


Figure 7 – Distribution of the concentration of dust pollution at the *AC* site (scenario 3)

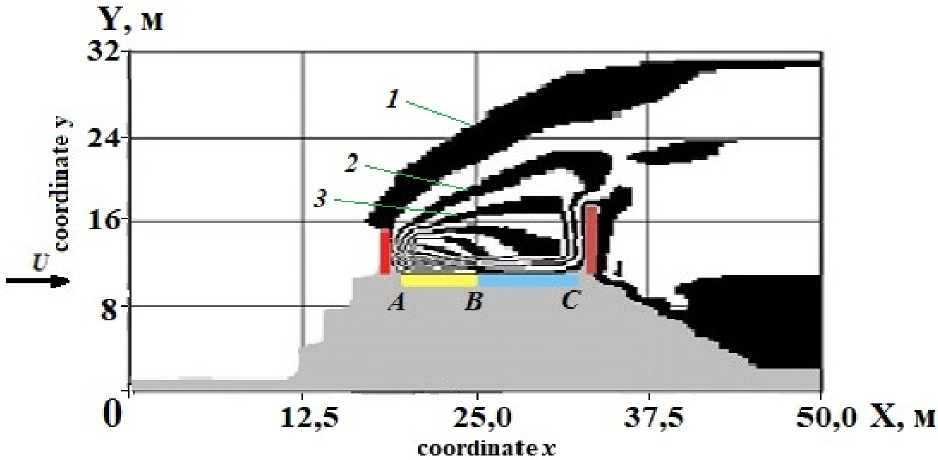
The analysis of Figure 6 shows that the pollution area with a significant dust concentration gradient is formed in the "cavern".

Figure 8 shows the pollution zone (scenario 4) when the screen on the left is *h*=3 m, but the height of the screen on the right is about *h*=6 m.

As can be seen from Figure 8, the second screen plays the role of a springboard and contributes to a more intensive rise of dust upwards than in the previous case.

Since the purpose of this work was a parametric study of the built numerical model, the calculation was performed with various parameters that are characteristic of the phenomenon being modeled. The following were varied: the position of the pollution source and its geometry; emission intensity of the emission; the height of the screens. This was done in order to check the stability of the numerical model.

Because, as is said above, in the area with complex boundary geometry, namely, when there is a large number of corner points inside the calculation area, streamlines with significant curvature are formed. In the work, the stability of the model was checked by performing computational experiments while varying the specified basic parameters. The article presents a small part of the research conducted by the authors.



1 – C=0.5 mg/m^3; *2* – C=2.53 mg/m^3; *3* – C=4.55 mg/m^3

Figure 8 – Zone of dust pollution (scenario 4, intensity of dust emission from the site Q=400 mg/s)

Figure 9 shows the distribution of dust concentration on the *AC* site, the approximating equation has the form: $y = -0.0061x^4 + 0.6739x^3 - 27.901x^2 + 509x - 3434.8$.

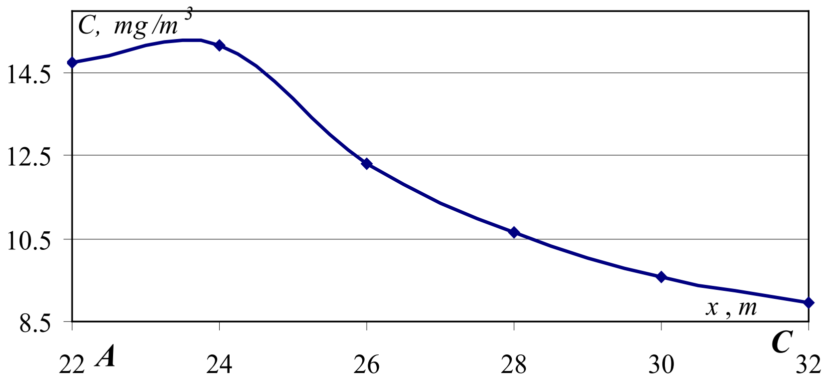


Figure 9 –Distribution of the concentration of dust pollution at the *AC* site (scenario 4)

4. Conclusions

The purpose of the research was achieved by creating a CFD model of the process of air pollution during the emission of dust from the tailings. The developed model is based on the numerical integration of the fundamental equations of the mechanics of a solid medium. The difference of the model is the use of the equation for the velocity potential when determining the velocity field of the air flow, instead of the equations of viscous fluid motion. As a result of the conducted research, the following conclusions can be made:

– no fictitious sources or drains appeared in the calculation area;

– pollution zones correspond to the physics of the process, namely, the formation of a clearly defined halo of pollution from a constantly operating source of pollution is observed;

– it can be clearly seen that there is the influence of the aerodynamics of the air flow on the formation of pollution zones, there is a rise of dust above the tailings storage;

– violation of the calculation stability when changing the input parameters of the problem was not detected;

– the calculation time of one scenario is 4 seconds.

The obtained results are necessary for conducting an express assessment of dust pollution of the air during its removal from the tailings storage, taking into account the location of pollution source, its type (point or linear), the shape of the tailings storage, the height of screens acting as means of reducing the dust load in the adjacent territory. The short calculation time of one scenario, the possibility of taking into account a significant number of physical and natural factors allows for a more detailed assessment of dust pollution level and the geometric parameters of means for its reduction.

A limitation of the model is the calculation of only 2D impurity distribution. Further research is the creation of a 3D CFD model for forecasting dust pollution.

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МАТЕМАТИЧНА МОДЕЛЬ ДЛЯ ЕКСПРЕС-ОЦІНЮВАННЯ ПРОЦЕСУ ПИЛОВОГО ЗАБРУДНЕННЯ ПОВІТРЯ БІЛЯ ХВОСТОСХОВИЩА

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Анотація. Великі площі земель відводяться на хвостосховища гірничозбагачувальних комбінатів. Вони стають джерелами інтенсивного пилоутворення після випуску хвостової пульпи і швидкого висихання за рахунок висоти укосів понад 40 м та значних швидкостей вітрового потоку на даних висотах. Подальший розвиток гірничо-збагачувальної галузі стає неможливим без впровадження екологічно-орієнтованих підходів до управління виробництвом та технологіями, що передбачає зменшення інтенсивності забруднення повітря. Оцінка зони забруднення є однією із глобальних проблем хвостосховищ, оскільки потребує врахування як фізичних, так і природних факторів. В даній роботі розроблено чисельну модель для експрес оцінювання пилового забруднення повітря при виносі пилу з хвостосховища. Чисельна модель базується на вирішенні рівняння гідродинаміки та рівняння масопереносу кінцево-різницевими методами. Рівняння Лапласа застосовується для знаходження потенціалу швидкості повітряного потоку, що дозволяє розрахувати поле швидкості в усій досліджуваній області. Розв'язання рівняння масопереносу дозволяє оцінити поле концентрації пилу, отримати наочне представлення концентрації у вигляді ізоліній. В дослідженні показано, що стійкість розрахунку при зміні вхідних параметрів задачі не порушується. Розроблена модель враховує геометрію укосів, місце розташування джерела пилу та його тип (точкове чи лінійне), зміну швидкості повітряного потоку з висотою, наявність екранів на вершинах укосів. Зони забруднення відповідають фізиці процесу, спостерігається формування чітко окресленого ореола забруднення від постійно діючого джерела забруднення, враховується вплив аеродинаміки повітряного потоку на формування зон забруднення. Отримані результати дослідження можуть бути корисними, як при оцінці зон пилового забруднення, так і при визначенні геометрії засобів захисту, а саме необхідної висоти екранів. Зниження рівня пилового забруднення до нормативних значень є необхідною умовою екологічно безпечного проживання населення в селітебних зонах.

Ключові слова: хвостосховище, пилове забруднення, математичне моделювання, чисельний експеримент, концентрація забруднення.

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