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ЕКОЛОГІЯ ТА ПРОМИСЛОВА БЕЗПЕКА

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NUMERICAL MODELING OF AIR POLLUTION FROM DUMPS

Purpose. Rock dumps are long-term sources of air pollution. A significant amount of harmful substances enters the atmosphere. Particularly intense is the pollution of atmospheric air due to dusting dumps. An important task is the development of methods for predicting the dynamics of atmospheric air pollution during the emission of harmful impurities from dumps. When developing methods for predicting the dynamics of air pollution from dumps. It is very important to create a universal model that would allow on a single computing platform to calculate the process of atmospheric air pollution for various impurities that are released from dumps. Another important problem is the choice of the place for optimal placement of future dumps in order to minimize their negative impact on the environment. **Methodology.** Numerical modeling of the formation of atmospheric pollution zones near rock dumps is based on the application of the equation of turbulent dispersion of an impurity in the atmosphere. To solve the problem of choosing the rational location of the dumps, the conjugate equation is used. Numerical integration is carried out using an implicit difference scheme. **Findings**. Numerical models are developed. The first numerical model allows one to evaluate the effect of rock dumps on air pollution. The second numerical model allows, on the basis of a one-time calculation, to determine the rational location of the future dump from the point of view of its minimal impact on air pollution. **Originality**. Two numerical models are proposed that are based on the application of the turbulent diffusion equation and the conjugate equation. These models make it possible to quickly determine the effect of rock dumps on air pollution. The models take into account the convective transport of the pollutant, atmospheric turbulent diffusion, the intensity of the emission of impurities from the dump. **Practical value**. The developed numerical models are implemented in the form of program codes. These program codes can be used when performing serial calculations on computers of low and medium power, i.e. computer technology, which is available to organizations involved in environmental issues in technologically saturated regions. When carrying out calculations based on the constructed numerical models, typical initial data are used regarding the intensity of the emission of impurities from dumps, weather conditions characteristic of a specific region of the country.

Keywords: air pollution; rock dumps; mathematical modelling; numerical models

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Introduction

It is known that the wide extraction of hard coal around the world started in the beginning of the XIX century, which is connected with the needs of economic development [2, 10]. The coal is obtained in various ways: in quarries and in mines. A characteristic feature of the development of both coal deposits and other minerals is the removal of large rock masses, the annual volumes of which are several times higher than the volumes of coal produced. These rocks also form numerous dumps represented by different species of rocks, which are heterogeneous in the granulometric composition. Depending on the technology of heaping, dumps of the following types are formed: conical (waste pits), spinal and flat. The areas of influence of the dumps exceed the area of the dumps several times. Landfills and waste heaps occupy about 165 thousand hectares, which is 2.5 % of the territory of Ukraine.

The harmful effect of rock dumps of coal mines on the environment has been investigated by many authors. Dumps of coal mines burn, dust, erode and are radioactive. As a result of physical and chemical weathering, the rock collapses, turns into dust, and together with combustible gases and a combustion site is one of the main sources of air pollution and deterioration of the sanitary condition of cities and working settlements of coal mines. For waste heaps, spontaneous combustion processes are typical in which up to 70 thousand tons of harmful substances per year enter the atmosphere: carbon monoxide, carbon dioxide, sulfur dioxide, sulfuric anhydride, hydrogen sulphide, carbon disulfide, carbon monoxide, nitrogen oxides, sulfuric acid, ammonia, cyanides, thiocyanates and others. Much attention is paid to the burning coal dumps in the whole world. Various geophysical methods and methods of GIS are used to find centers of ignition . Gases entering the atmosphere from the dumps change the composition of atmospheric air, which significantly affects the soil and vegetation cover, the animal world, the productivity of land in adjacent areas to the dumps. At burning of 1 kg of a rock there is a pollution of atmospheric air in volume of 6.7-8.7 million m^3. An assessment of the effect of dumps on the environment in the study of physical and mechanical properties of rocks was carried out.

There are neighboring villages in the zone of the dumps influence, in this connection an active issue is the assessment of the harmful impact of dumps on the environment and, first of all, on the level of air pollution. For this evaluation, the OND-86 model is used, which completely does not allow taking into account the parameters of the stability of the atmosphere, the change in the value of wind speed to the formation of pollution zones. In the world practice, more universal mathematical models based on solving the equations of convective-diffusion dispersion of an impurity in atmospheric air are used to solve problems of assessing the influence of dumps on atmospheric air pollution.

At present, the regularities of the effect of dumps from coal mines on the environment have been clarified both during their operation and after the elimination of mines. Methodological approaches to the comprehensive environmental assessment of the impact of coal mine dumps on the environment have been improved. It was shown that an effective approach is based on adequate models of wind flow around dumps and convective-diffusion transfer of dust-gas impurities in the area of the dumps.

The main source of air pollution of adjacent areas to the dumps is their burning and dusting.

Around 60-75 % of conical and 17-37 % of flat dumps are subjected to spontaneous combustion, more than 500 thousand tons of gaseous substances are emitted from their surfaces annually. Namely, about 9.758 kg of CO, 154170 kg of CO_2, 1476 kg of SO_2, 339 kg of H_2S, 72 kg of $NO+NO_2$ enter the atmosphere per day from burning rock dumps of mines and concentrating factories of Donbas. Accumulation of these substances is the cause of environmental problems such as «destruction of the ozone layer» and «greenhouse effect». In addition, more than 400 tons of rocks that contain toxic elements (*Hg*, *Pb, As*, *Se*, *Cd*, *Ni*, *Mo*, *Zn*, *Mn*, *V*, *Be*, etc.) are blown into each of the adjacent territories. A burning rock dump has a sanitary protection zone of 500 m, a non-combustible zone –300 m, a separation of harmful substances and combustion products – up to 3 km. From this it can be concluded that living in the territories located in the vicinity of waste tanks is dangerous for life and health.

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It is known that conducting experiments to investigate the formation of contamination zones is a fairly time-consuming process, Computational Fluid Dynamics (CFD) modeling is performed with the help of expensive commercial packages ISC3, Aermod, Fluent, CFX, etc [3, 6–9]. Many numerical calculations are performed on the basis of the Lagrange and Gauss models and their various modifications [9, 11].

The aim of this work is the development of a numerical model for assessing the impact of dumps on air pollution in nearby settlements and the possible location of the dump so that its negative impact is minimal on the areas under consideration. The proposed model can be used to predict air pollution in the event of a possible ignition of the waste water when a significant amount of harmful substances enters the atmosphere.

Purpose

The aim of the work is to develop computing numerical models to assess dumps influence on air pollution and to solve the problem of choosing of rational dump location.

Methodology

In this paper, the solution of two problems is considered related to the simulation of atmospheric air pollution from dumps.

Direct problem. A direct problem is to simulate atmospheric air pollution from the dump at a known value of its location coordinates. It can be project coordinates, that is the location where the dump is supposed to be located, or the coordinates of an already existing dump. To simulate the spread of gaseous emissions from dumps, the mass transfer equation (1) is used. In many works the rock dump is considered as a point-like object of pollution, in this work the blade is modeled by a set of point sources specified by the Dirac function, so it is reduced to an area source.

The meteorological situation parameters specific for the particular region where the dumps are located are determined based on the processing of observational data or based on the application of meteorological forecast data [1–4, 6, 12]

$$\frac{\partial C}{\partial t}+\frac{\partial uC}{\partial x}+\frac{\partial vC}{\partial y}+\sigma C=$$

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

$$+\sum_{i=1}^{n}Q_i(t)\delta(x-x_i)\delta(y-y_i),\quad (1)$$

where C is the concentration of the pollutant (dust or gaseous impurity) (mg/m^3); u, v – averaged values of the components of the velocity vector of the air flow (m/s); σ – coefficient that takes into account the rate of settling of the impurity and interaction with the earth's surface (1/s), $\mu=(\mu_x,\mu_y)$ – the coefficients of turbulent diffusion (m/s^2); x_i, y_i – coordinates of point sources of pollutant receipt (m); Q_i – the averaged value of the intensity of the impurity from the dump at the location of the point source (mg/s); $\delta(x-x_i)\delta(y-y_i)$ – Dirac delta function, which simulates the flow of pollutant from an area source.

The coefficient σ, according to Marchuk, can be represented in the form $\sigma=\sigma_1+\sigma_2+\sigma_3$, where σ_1 is the coefficient taking into account the chemical transformation of the impurity in the atmosphere, $\sigma_2=\omega_g/H$ is a coefficient taking into account the ratio of gravitational settling velocity of the pollutant (dust) ω_g, m/s to the averaging height H = 600÷800 m, $\sigma_3=\mu_z/H$ is the coefficient taking into account the turbulent interaction of the pollutant and underlying surface.

The intensity of admixture intake from dumps can be estimated on the basis of experimental data or developed methods [4]. For example, the intensity of dust emission (tons/day) from inactive dumps can be estimated on the basis of empirical dependence:

$$Q=2\cdot10^{-5}\cdot S,\quad (2)$$

where S is the surface area of the dump (m^2).

Calculation of emissions (tons/day) from dumps not operating for less than three years is calculated using the formula:

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$$P_p = f \cdot P, \quad (3)$$

where P_p – the amount of polluting gases released from the dumps after the operation is finished (tons/day); P – amount of polluting gases released from the dumps during operation (tons/day) (4); f – coefficient, depending on the time during which the dump does not work.

After 1 year $f = 0,5$; after 2 years $f = 0,3$; after 3 years $f = 0,1$ (then the allocation becomes insignificant).

Calculation of gases emissions (tons/day) from existing burning slagheap and spinal heap are calculated according to the formula:

$$P = 0.001 \cdot m \cdot H \cdot D, \quad (4)$$

where m is the coefficient depending on the quality of coal (Table 1.), H – height of dump (m); D – the amount of rock that is given to the dump (tons/(m·day).

Table 1

The values of the coefficient m

Contaminant	Donets basin	Lviv-Volyn basin
Carbon monoxide, CO	0,2	2,0
Carbon dioxide, CO_2	2,5	9,3
Sulfur dioxide, SO_2	0,02	0,5
Hydrogen sulfide, H_2S	0,01	0,03
Nitrogen oxides, $NO+NO_2$	0,002	0,006

Calculation of emissions (tons/day) for gases from burning flat dumps is calculated using the formula:

$$P = 0,001 \cdot q \cdot \left(0,036 \cdot S + 0,052 \cdot \sqrt{S} \cdot x \cdot H\right), \quad (5)$$

where q – specific gas emission (kg/(m2 day)); for CO, $q = 7,6$; for CO2, q=138; for SO2, $q = 1,7$; for H2S, $q = 0,5$; for NO + NO2, $q = 0,12$; S – the area of the base of the flat blade (m2); H – is the average height of the dump (m).

For the numerical solution of equation (1), an alternating-triangular implicit difference splitting scheme is used [1, 2, 6]. Consider the principle of constructing of this scheme.

Convective derivatives can be represented as:

$$\frac{\partial uC}{\partial x} = \frac{\partial u^+ C}{\partial x} + \frac{\partial u^- C}{\partial x},$$

$$\frac{\partial vC}{\partial y} = \frac{\partial v^+ C}{\partial y} + \frac{\partial v^- C}{\partial y},$$

where

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

To approximate convective derivatives, we use the expressions:

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

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

$$\frac{\partial v^+ C}{\partial y} \approx \frac{v^+_{i,j+1} C^{n+1}_{i,j} - v^+_{i,j} C^{n+1}_{i,j-1}}{\Delta y} = L^+_y C^{n+1},$$

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

The second derivatives are approximated by the following expressions:

$$\frac{\partial}{\partial x}\left(\mu_x \frac{\partial C}{\partial x}\right) \approx \tilde{\mu}_x \frac{C^{n+1}_{i+1,j} - C^{n+1}_{i,j}}{\Delta x^2} - \tilde{\mu}_x \frac{C^{n+1}_{i,j} - C^{n+1}_{i-1,j}}{\Delta x^2} =$$

$$= M^-_{xx} C^{n+1} + M^+_{xx} C^{n+1},$$

$$\frac{\partial}{\partial y}\left(\mu_y \frac{\partial C}{\partial y}\right) \approx \tilde{\mu}_y \frac{C^{n+1}_{i,j+1} - C^{n+1}_{i,j}}{\Delta y^2} - \tilde{\mu}_y \frac{C^{n+1}_{i,j} - C^{n+1}_{i,j-1}}{\Delta y^2} =$$

$$= M^-_{yy} C^{n+1} + M^+_{yy} C^{n+1}.$$

$$\frac{\partial}{\partial x}\left(\mu_x \frac{\partial C}{\partial x}\right) \approx \tilde{\mu}_x \frac{C^{n+1}_{i+1,j} - C^{n+1}_{i,j}}{\Delta x^2} - \tilde{\mu}_x \frac{C^{n+1}_{i,j} - C^{n+1}_{i-1,j}}{\Delta x^2} =$$

$$= M^-_{xx} C^{n+1} + M^+_{xx} C^{n+1},$$

$$\frac{\partial}{\partial y}\left(\mu_y \frac{\partial C}{\partial y}\right) \approx \tilde{\mu}_y \frac{C^{n+1}_{i,j+1} - C^{n+1}_{i,j}}{\Delta y^2} - \tilde{\mu}_y \frac{C^{n+1}_{i,j} - C^{n+1}_{i,j-1}}{\Delta y^2} =$$

$$= M^-_{yy} C^{n+1} + M^+_{yy} C^{n+1}.$$

With these notations taken into account, the difference analog of the impurity transport equation (1) has the form:

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$$\frac{C_{\mathrm{i,j}}^{\mathrm{n+1}}-C_{\mathrm{i,j}}^{\mathrm{n}}}{\Delta t}+L_{\mathrm{x}}^{+}\cdot C^{\mathrm{n+1}}+L_{\mathrm{x}}^{-}\cdot C^{\mathrm{n+1}}+$$

$$+L_{\mathrm{y}}^{+}\cdot C^{\mathrm{n+1}}+L_{\mathrm{y}}^{-}\cdot C^{\mathrm{n+1}}+\sigma\cdot C_{\mathrm{i,j}}^{\mathrm{n+1}}=$$

$$=(M_{\mathrm{xx}}^{+}\cdot C^{\mathrm{n+1}}+M_{\mathrm{xx}}^{-}\cdot C^{\mathrm{n+1}}+$$

$$+M_{\mathrm{yy}}^{+}\cdot C^{\mathrm{n+1}}+M_{\mathrm{yy}}^{-}\cdot C^{\mathrm{n+1}}). \quad (6)$$

Integration over a time interval splits equation (6) as follows:

– at the first time step $k = n + 1/4$:

$$\frac{C_{\mathrm{i,j}}^{\mathrm{k}}-C_{\mathrm{i,j}}^{\mathrm{n}}}{\Delta t}+\frac{1}{2}\left(L_{\mathrm{x}}^{+}\cdot C^{\mathrm{k}}+L_{\mathrm{y}}^{+}\cdot C^{\mathrm{k}}\right)+\frac{\sigma}{4}C_{\mathrm{i,j}}^{\mathrm{k}}=$$

$$=\frac{1}{4}\left(M_{\mathrm{xx}}^{+}\cdot C^{\mathrm{k}}+M_{\mathrm{xx}}^{-}\cdot C^{\mathrm{n}}+M_{\mathrm{yy}}^{+}\cdot C^{\mathrm{k}}+M_{\mathrm{yy}}^{-}\cdot C^{\mathrm{n}}\right);(7)$$

– at the second time step $k = n + 1/2$; $c = n + 1/4$:

$$\frac{C_{\mathrm{i,j}}^{\mathrm{k}}-C_{\mathrm{i,j}}^{\mathrm{c}}}{\Delta t}+\frac{1}{2}\left(L_{\mathrm{x}}^{-}\cdot C^{\mathrm{k}}+L_{\mathrm{y}}^{-}\cdot C^{\mathrm{k}}\right)+\frac{\sigma}{4}C_{\mathrm{i,j}}^{\mathrm{k}}=$$

$$=\frac{1}{4}\left(M_{\mathrm{xx}}^{-}\cdot C^{\mathrm{k}}+M_{\mathrm{xx}}^{+}\cdot C^{\mathrm{c}}+M_{\mathrm{yy}}^{-}\cdot C^{\mathrm{k}}+M_{\mathrm{yy}}^{+}\cdot C^{\mathrm{c}}\right);(8)$$

– at the third time step $k = n + 3/4$; $c = n + 1/2$ the formula (7) is used, in the fourth time step $k = n + 1$; $c = n + 3/4$ the formula (8) is used, in the fifth step the formula:

$$\frac{\overset{5\,n+1}{C}_{i,j}-\overset{5\,n}{C}_{i,j}}{\Delta t}=\sum_{i=1}^{N}\frac{Q_i\left(t^{n+1/2}\right)}{\Delta x\Delta y}\cdot\delta_i. \quad (9)$$

A feature of this difference scheme is that an unknown value of the impurity concentration at each step of the splitting is found by the explicit scheme of the running count. Based on the difference equations, the «FORW-2D» code was developed.

Direct problem. Under this task, the situation is considered when it is necessary to find the location of the dump so that its negative impact on the objects under consideration is minimal. Namely, the concentration of the pollutant coming from the dump at the locality point of the settlement should not exceed a certain predetermined value $C(x,y)\le C_n$, where C_n – MAC for populated areas.

To solve this problem, we can use equation (1) and sequentially choose different coordinates, different positions of the dump, by finding the solution of the problem by the search method. However, this process requires lots of calculations, since it is necessary to solve equation (1) many times to determine the pollutant concentration field in the settlement for different variants of the dump placement. More effective is the approach proposed by academician Marchuk, which is based on the solution of the conjugate equation (10) [3]

$$-\frac{\partial C^*}{\partial t}-\frac{\partial uC^*}{\partial x}-\frac{\partial vC^*}{\partial y}+\sigma C^*=$$

$$=\frac{\partial}{\partial x}(\mu_{\mathrm{x}}\frac{\partial C^*}{\partial x})+\frac{\partial}{\partial y}(\mu_{\mathrm{y}}\frac{\partial C^*}{\partial y})+p, \quad (10)$$

where C^* is the function conjugated with a function C (mg/m^3), p is a certain function.

The boundary conditions for the conjugate problem have the form:

- $C^*=C_T^*$ – concentration of pollutant in ambient air at $t=T(s)$;
- $C^*=0$ – at the boundaries of the calculated area.

The form of the function p can be extremely diverse, for example [3]:

$$p(x,y,t)=\delta(x-x_0)\delta(y-y_0)\delta(t-t_i)\cdot C_T^*, \quad (11)$$

If a solution of the conjugated equation (10) is found, then it is necessary to find the value of the functional of the following form [3]:

$$I=Q\int_0^T C^*(x_0,y_0,t)\,dt. \quad (12)$$

Having constructed the isolines of this functional, the solution of the problem is sought from the condition [3]:

$$I(x_0,y_0,t)<\varphi, \quad (13)$$

where φ is maximum permissible value of potential I.

To solve the conjugated problem (10), new variables are introduced:

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$$u' = -u, v' = -v, t' = T - t.$$

The solution of the conjugated problem starts from the moment of time $t = T$, the calculation proceeds in the opposite direction of time. To solve equation (10), we use the alternate-triangular implicit difference scheme considered above, that is, an unknown value C^* is found by an explicit scheme of the running account. Based on this algorithm, the code «BACK-2D» was developed. This code is aimed to solve the problem of justifying the location of the dump.

Findings

The developed codes were used to solve two problems. The first problem is the calculation of the atmospheric air pollution zone with carbon monoxide using the proposed numerical model. The source of pollution are the dumps of the West-Donbas mine, the characteristic dimensions of the occupied territory are 860 m by 415 m according to the map. With the possible spontaneous combustion of these dumps, more than 10 tons/day of carbon monoxide can enter the atmosphere. The West-Donbas mine is a coal mining enterprise in the town of Ternivka, Dnipropetrovsk region (Ukraine), commissioned since 1979, is included in the PAO «Ternove» mine management of «DTEK Pavlohradvuhillya» (DTEK) from 2013, the largest mine in the Western Donbass. The calculation was carried out with the following parameters: the dimensions of the computed area were 4 km per 2 km, the wind velocity was $U = 6$ m/s with the south-west direction (Fig. 1), $C_{\text{мах}}$=18.381 mg/m^3 with steady flow regime.

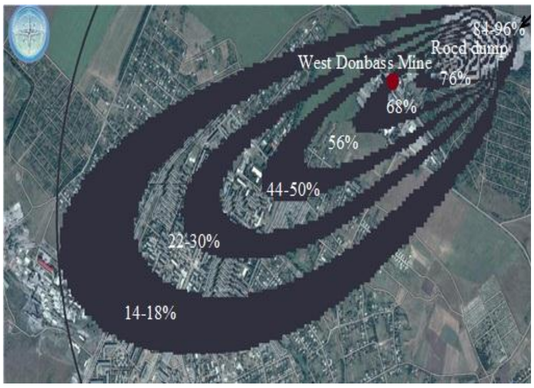

Fig. 1. Percentage distribution of carbon monoxide concentration in the contaminated zone

The concentration value is represented as a percentage of its maximum value at the calculated time. Calculations showed that the maximum value of the concentration $C_{\text{мах}}$=18.381 mg/m^3 can exceed maximum allowable concentration (maximum one-time) *MACm.t.*=5 mg/m^3, but the distribution of concentration decreases from the center of the pollutant supply source (mine dumps) to the periphery. The percentage distribution of the concentration is shown in Figure 1, there are in the pollution zone: dumps – 96-76 %; the mine and its territory – 76-58 %; Molodizhna Str., Ivan Franko Str., Maiakovskoho Str. – 56-44 %; Lermontova Str., Dniprovs’ka Str. – 42-30 %; Zhovtneva Str., Spas’ka Str., Michurina Str. – 26-10 %. On the territory that limits the calculated zone of pollution, and outside of it the concentration of carbon monoxide is 5-10 % or less. In Figure 1, a general zone of contamination is shown in the circle, which can occur when the meteorological parameters change, namely the direction of the velocity.

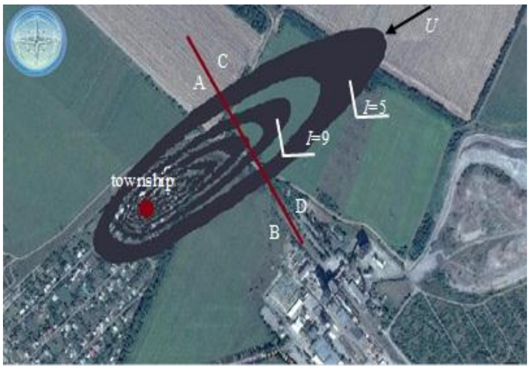

Fig. 2. Isolines of the functional *I*, which justify the choice of possible placement of the dump

The presentation of modeling results by imposition of contamination zones on a map of the territory, that is near to the source of pollution allows us to determine quickly the boundaries of zones of technogenic pollution and their variation under different meteorological conditions and different intensities of the pollutant.

The second problem is to select the location of the dump based on the solution of the conjugated equation. To illustrate the practical application of this approach, Figure 2 shows the isolines of the functional (12), determined after solving the

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conjugated equation (10), which allow to determine the possible location of the dump, so that the negative impact on the village was minimal.

The isoline $I = 5$ shows that if the dump is placed along this line, then in the village the concentration of CO in the air will be 5 mg/m^3. If the dump is placed on the line $I = 9$, this means that the CO concentration in the air is 9 mg/m^3, it will exceed *MACm.t*. So, having made only one calculation based on the conjugate equation, it is possible to obtain an area where it is recommended to have a dump to minimize its influence on the level of air pollution in the village.

From the mathematical point of view, the influence of the dump on the air pollution in the village will be the same for any of its location along the line $I = \text{const}$ ($I = 5$). However, from a practical point of view, it is necessary to divide the obtained picture of the isolines distribution of the functional I into two parts Figure 3. The section A-B should be excluded from consideration, because if the dump is located on this site, when the wind direction in the village changes, intensive air pollution will occur, so it makes sense to put a dump in the C-D section. So, a computational experiment carried out to determine the functional lines, taking into account the practically possible location of the dump, allows us to refine the coordinates of the dump by solving the direct problem using equation (1).

Originality and practical value

Two numerical models were developed to predict atmosphere pollution from dumps of breed. The first model is based on equation of pollutant convective – diffusive transfer. The second model is based on the equation of conjugate problem. Numerical integration of modeling equations is performed using implicit difference scheme of spiting. The developed models can be used for quick assessment of dumps influence on air pollution and to solve the problem of choosing of rational dump location.

Conclusions

As a result of the research, the following results were obtained:

1. A mathematical model is proposed for the «express» forecast of the level of air pollution in the impact zone of mine dumps, which is based on the numerical integration of the equation of convective-diffusion dispersion of an impurity in the atmosphere. For numerical integration of the modeling equation, an implicit difference splitting scheme is used, representing the balance of the impurity mass for each difference cell. The unknown value of the impurity concentration is determined by the running account method, which allows a simple software implementation of the difference relations.

The proposed model has a significant advantage over the currently used normative methodology of OND-86. The peculiarity of the model is the efficiency in obtaining forecast data. The model takes into account the main physical factors affecting the formation of contamination zones. This model is implemented in the form of the program code «FORW-2D».

2. A mathematical model has been developed for solving the problem of scientifically justified selection of the mine dump location with the condition of a minimum level of air pollution in ecologically significant areas (villages for workers, residential areas).

This model is based on solving the conjugate equation, which allows to determine the position of the dump based on a one-time calculation. This model is implemented in the form of the program code «BACK-2D».

3. The solution of the problem of assessing the impact of mine dumps on the level of atmospheric air pollution, as well as on justifying the location of the dump, requires 2 seconds of computer time. This is important for carrying out serial calculations in the centers for environmental protection.

4. The perspective of development in this direction is the working out of a 3D numerical model for predicting the formation of pollution zones near the dumps taking into account their geometric shape.

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ЧИСЕЛЬНЕ МОДЕЛЮВАННЯ ЗАБРУДНЕННЯ ПОВІТРЯНОГО СЕРЕДОВИЩА ВІД ВІДВАЛІВ

Мета. Відвали породи є довгостроковими джерелами забруднення атмосферного повітря. В атмосферу надходить значна кількість шкідливих речовин. Особливо інтенсивно відбувається забруднення атмосферного повітря внаслідок цвітіння відвалів. Важливим завданням є розробка методів прогнозу динаміки забруднення атмосферного повітря при виділенні шкідливих домішок від відвалів. При розробці методів прогнозу динаміки забруднення повітряного середовища від відвалів. Дуже важливим є створення універсальної моделі, яка дозволяла б на єдиній обчислювальної платформі здійснювати розрахунок процесу забруднення атмосферного повітря для різних домішок, які виділяються від відвалів. Також важливою проблемою є вибір місця оптимального розміщення майбутніх відвалів, з метою мінімізації їх негативного впливу на навколишнє середовище. **Методика.** Чисельне моделювання формування зон забруднення атмосфери біля відвалів породи виконано на основі застосування рівняння турбулентного розсіювання домішки в атмосфері. Для вирішення задачі по вибору раціонального місця розташування відвалів використовується зв'язане рівняння. Чисельне інтегрування здійснюється за допомогою неявної різницевої схеми. **Результати**. Розроблено чисельні моделі. Перша чисельна модель дозволяє оцінити вплив відвалів породи на забруднення атмосферного повітря. Друга чисельна модель дозволяє на основі одноразового розрахунку визначити раціональне місце розташування майбутнього відвалу з точки зору його мінімального впливу на забруднення атмосферного повітря. **Наукова новизна.** Запропоновано дві чисельні моделі, які ґрунтуються на застосуванні рівняння турбулентної дифузії і зв'язаного рівняння. Дані моделі дозволяють оперативно визначити вплив відвалів породи на забруднення атмосферного повітря. Моделі враховують конвективний перенос забруднювача, атмосферну турбулентну дифузію, інтенсивність емісії домішки від відвалу. **Практична значимість.** Розроблені чисельні моделі імплементовані у вигляді програмних кодів. Дані програмні коди можуть бути використані, при проведенні серійних розрахунків на комп'ютерах малої і середньої потужності, тобто обчислювальної техніки, яка є в розпорядженні організацій, що займаються екологічними проблемами в техногенно насичених регіонах. При проведенні розрахунків на базі побудованих чисельних моделей використовуються типові вихідні дані щодо інтенсивності емісії домішок від відвалів, метеоумови, характерні для конкретного регіону країни.

Ключові слова: забруднення атмосфери; відвали породи; математичне моделювання; чисельні моделі

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ЧИСЛЕННОЕ МОДЕЛИРОВАНИЕ ЗАГРЯЗНЕНИЯ ВОЗДУШНОЙ СРЕДЫ ОТ ОТВАЛОВ

Цель. Отвалы породы являются долгосрочными источниками загрязнения атмосферного воздуха. В атмосферу поступает значительное количество вредных веществ. Особо интенсивно происходит загрязнение атмосферного воздуха вследствие пыления отвалов. Важной задачей является разработка методов прогноза динамики загрязнения атмосферного воздуха при выделении вредных примесей от отвалов. При разработке методов прогноза динамики загрязнения воздушной среды от отвалов. Очень важным является создание универсальной модели, которая позволяла бы на единой вычислительной платформе осуществлять расчет процесса загрязнения атмосферного воздуха для различных примесей, которые выделяются от отвалов. Также важной проблемой является выбор места оптимального размещения будущих отвалов, с целью минимизации их отрицательного влияния на окружающую среду. **Методика.** Численное моделирование формирования зон загрязнения атмосферы возле отвалов породы выполнено на основе применения уравнения турбулентного рассеивания примеси в атмосфере. Для решения задачи по выбору рационального места расположения отвалов используется сопряженное уравнение. Численное интегрирование осуществляется с помощью неявной разностной схемы. **Результаты.** Разработаны численные модели. Первая численная модель позволяет оценить влияние отвалов породы на загрязнение атмосферного воздуха. Вторая численная модель позволяет на основе одноразового расчета определить рациональное место расположения будущего отвала с точки зрения его минимального влияния на загрязнение атмосферного воздуха. **Научная новизна**. Предложены две численные модели, которые основываются на применении уравнения турбулентной диффузии и сопряженного уравнения. Данные модели позволяют оперативно определить влияние отвалов породы на загрязнение атмосферного воздуха. Модели учитывают конвективный перенос загрязнителя, атмосферную турбулентную диффузию, интенсивность эмиссии примеси от отвала. **Практическая значимость.** Разработанные численные модели имплементированы в виде программных кодов. Данные программные коды могут быть использованы, при проведении серийных расчетов на компьютерах малой и средней мощности, т.е. вычислительной технике, которая имеется в распоряжении организаций, занимающихся экологическими проблемами в техногенно насыщенных регионах. При проведении расчетов на базе построенных численных моделей используются типовые исходные данные относительно интенсивности эмиссии примесей от отвалов, метеоусловия, характерные для конкретного региона страны.

Ключевые слова: загрязнение атмосферы; отвалы породы; математическое моделирование; численные модели

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