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DETERMINATION OF THE PROBABILITY FACTOR OF PARTICLES MOVEMENT IN A GAS-DISPERSED TURBULENT FLOW

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Abstract. *The goal of the work is to define the probability factor of particles movement in a gas-dispersed turbulent flow. The object of the research is the description of harmful impurities transfer process in the atmosphere with the help of mathematical modelling of variability of gas and aerosol composition of atmosphere. Another object is assessment atmospheric impurities on the environment. The novelty of the research is that probability-statistical approach is used in modelling the transfer of harmful impurities from anthropogenic sources into the atmosphere.*

Keywords: probability factor of particles movement, transfer of harmful impurities, environment, anthropogenic sources, pollutions, information system.

WYZNACZENIE WSPÓŁCZYNNIKA PRAWDOPODOBIEŃSTWA RUCHU CZĄSTEK STAŁYCH W TURBULENTNYM PRZEPŁYWIE DYSPERSYJNYM W FAZIE GAZOWEJ

Streszczenie. *Celem pracy jest określenie współczynnika prawdopodobieństwa ruchu cząstek w przepływie turbulentnym dyspersyjnym w gazie. Celem pracy jest opisanie procesu przenoszenia szkodliwych zanieczyszczeń do atmosfery za pomocą matematycznego modelowania zmienności składu gazów i aerozoli atmosferycznych oraz ocena wpływu zanieczyszczeń atmosferycznych na środowisko. Nowością tych badań jest zastosowanie probabilistycznego i statystycznego podejścia do modelowania transferu szkodliwych zanieczyszczeń ze źródeł antropogenicznych do atmosfery.*

Słowa kluczowe: współczynnik prawdopodobieństwa ruchu cząstek, transfer szkodliwych zanieczyszczeń, środowisko, źródła antropogeniczne, zanieczyszczenia, system informacyjny

Introduction

Anthropogenic sources of pollution influence the environment and affects the state of air basin. The problems of air basin protection are included in a wide research area on the junction of several sciences. Pollution of atmosphere surface layer is the most relevant problem nowadays.

The pattern of flow and dissemination of harmful substances and their compounds that locally contaminate air surface layer considerably differs from these phenomena in fee atmosphere. The solution of scientific and applied problems of environment protection requires detailed description of processes of harmful substances dissemination in air basin of industrial regions. Recently, these problems have become urgent especially in large industrial cities due to the activities of big industrial enterprises.

Experimental researches in this sphere are connected with significant investments and hampered due to large spatial scale of the process. Besides, the experiment enables to build up situation forecast in case of atmospheric conditions change (speed and direction of wind, atmospheric pressure) Mathematical modeling in this direction enables to track and forecast impurities dissemination in atmosphere surface layer taking into account real conditions of a region and change of meteorological parameters that will help to make due administrative decisions.

Long term experience in studying air pollution have been accumulated, natural experiments on control of impurities dissemination have been carried out, and basic regularities of transfer have been obtained [1]. Accuracy of models intended for calculation of impurities dissemination in atmosphere is the main thing for environment protection activities. Calculation methods for impurities dissemination in atmosphere is basically suitable for the conditions of thermally uniform and smooth relief [7, 8].

The relevance of this work is determined by the necessity to model pollution of air basin of industrial centres for complex study of pollutants dynamics in air basin of certain region, by providing the opportunity to carry out computational experiments taking into account the current information, and by studying different situations within the frameworks of the chosen scenario.

1. Determination of the probability factor of particles movement

The given article considers determination of the probability factor of particles movement in a gas-dispersed turbulent flow of atmospheric boundary layer for probable – statistical model described in the work [8].

The work [8] considered impurity particles movement as a sequence of step movements that are h long in small periods of time Δt in one of four possible directions on the vertical plane.

Movement directions were defined every time by corresponding probabilities p_i: p_{+x}, p_{-x}, p_{+y}, p_{-y}, and naturally in accordance with normalization requirement that is at any moment of time

$$p_{+x}(t) + p_{-x}(t) + p_{+y}(t) + p_{-y}(t) = 1 \tag{1}$$

Applying approximants for recurrent Poissonian flow of events and law of large numbers, passing to the limit when $\Delta t \to 0$ and adding the function describing sources of harmful impurities emissions we have got the following equation in the plane (x, z):

$$\begin{aligned}\frac{\partial \phi}{\partial t} = {} & \mu_{+x,i,j}\left(\phi^n_{i-1,j} - \phi^n_{i,j}\right) + \\ & + \mu_{-x,i,j}\left(\phi^n_{i+1,j} - \phi^n_{i,j}\right) + \\ & + \mu_{+z,i,j}\left(\phi^n_{i,j-1} - \phi^n_{i,j}\right) + \\ & + \mu_{-z,i,j}\left(\phi^n_{i,j+1} - \phi^n_{i,j}\right) + f\end{aligned} \tag{2}$$

The equation (2) is identical to difference analogue of transfer equations. Difference analogue of transfer equations in continuous medium can be in the following form taking into account diffusion process and using the scheme accounting the sign:

$$\begin{aligned}\frac{\varphi^{n+1}_{i,j} - \varphi^n_{i,j}}{\tau} = {} & \left[\frac{\mu_x}{h_1^2} + \frac{u+|u|}{2h_1}\right]\left(\varphi^n_{i-1,j} - \varphi^n_{i,j}\right) + \\ & + \left[\frac{\mu_x}{h_1^2} + \frac{u-|u|}{2h_1}\right]\left(\varphi^n_{i+1,j} - \varphi^n_{i,j}\right) + \\ & + \left[\frac{\mu_z}{h_2^2} + \frac{w+|w|}{2h_2}\right]\left(\varphi^n_{i,j-1} - \varphi^n_{i,j}\right) + \\ & + \left[\frac{\mu_z}{h_2^2} + \frac{w-|w|}{2h_2}\right]\left(\varphi^n_{i,j+1} - \varphi^n_{i,j}\right) + f_{i,j}\end{aligned}$$

It is seen to be that transitions intensity $\mu_{+x,i,j}, \mu_{-x,i,j}, \mu_{+z,i,j}$ and $\mu_{-z,i,j}$ are defined as follows

$$\mu_{+x} = \frac{\mu_x}{h_1^2} + \frac{u+|u|}{2h_1}, \quad \mu_{-x} = \frac{\mu_x}{h_1^2} - \frac{u-|u|}{2h_1}, \qquad (3)$$
$$\mu_{+z} = \frac{\mu_z}{h_2^2} + \frac{w+|w|}{2h_2}, \quad \mu_{-z} = \frac{\mu_z}{h_2^2} - \frac{w-|w|}{2h_2}$$

Instantaneous speed of atmosphere at any point of the flow in every direction can be presented as the sum of average speed and pulsation speed:

$$u = \bar{u} + u', \; w = \bar{w} + w' \qquad (4)$$

where $\bar{u}, \bar{w}$ are components of wind speed, u', w' – stochastic process. When there is no wind in atmosphere, intensity of turbulent pulsations can be considered equal in all directions, i.e. $\mu_x = \mu_z$, so probabilities of movement can also be considered equal, i.e. $u' = w'$.

When equations (2) were calculated, transitions intensity $\mu_{+x,i,j}, \mu_{-x,i,j}, \mu_{+z,i,j}$ and $\mu_{-z,i,j}$ were defined according to (3) taking into account normalization requirements (1). Such approach provides implementing the terms of mass conservation and enables to define the amount of emitted pollutants into the atmosphere for certain period of time.

During numerical simulations two boundary conditions were taken into account:
first – free boundary

$$\left.\frac{\partial \phi}{\partial t}\right|_{x=X} = \mu_{+x,m_1,j}\left(\phi^n_{m_1-1,j} - \phi^n_{m_1,j}\right) + \mu_{-x,m_1,j}\left(-\phi^n_{m_1,j}\right) + \mu_{+z,m_1,j}\left(\phi^n_{m_1,j-1} - \phi^n_{m_1,j}\right) + \mu_{-z,m_1,j}\left(\phi^n_{m_1,j+1} - \phi^n_{m_1,j}\right) + f \qquad (5)$$

it means that impurity flows out easily but doesn't flow in. Thus, if it is required, we can define amount of impurities that were brought out from computational region for self-purification with wind regimes and second – solid boundary.

$$\left.\frac{\partial \phi}{\partial t}\right|_{z=0} = \mu_{+x,i,1}\left(\phi^n_{i-1,1} - \phi^n_{i,1}\right) + \mu_{-x,i,1}\left(\phi^n_{i+1,1} - \phi^n_{i,1}\right) + \mu_{+z,i,j}\left(-\phi^n_{i,1}\right) + \mu_{-z,i,1}\left(\phi^n_{i,2}\right) + f \qquad (6)$$

in this case the impurity neither flows in nor flows out. In the same way it is possible to get boundary conditions for other boundaries of the considered area.

2. Results

The model that was described above with the help of probability-stochastic approaches was used for defining transition intensity. This helped to carry out methodological calculations of point and linear sources.

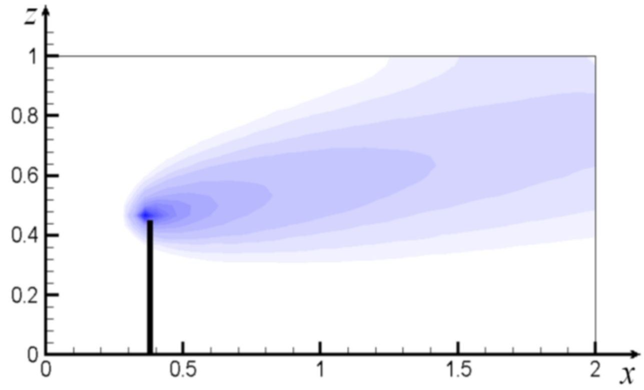

Fig. 1. Wind speed 1 m/s, point source

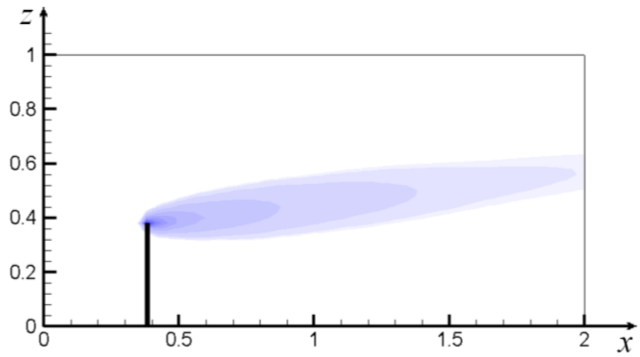

Fig. 2. Wind speed 3 m/s, point source

When model for dissemination of harmful impurities from stationary sources (Figures 1 and 2) is used, the influence of wind speed regime can be seen well. When wind speed is 1 m/s the transfer process goes on more slowly and influence of diffusion processes (Figure 1) is evident. When wind speed is 3 m/s impurity is carried away faster, avoiding diffusion processes influence (Figure 2).

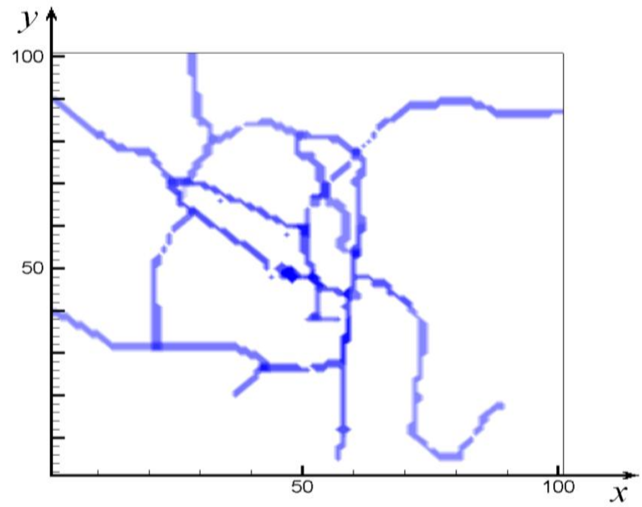

Fig. 3. Input data of linear source

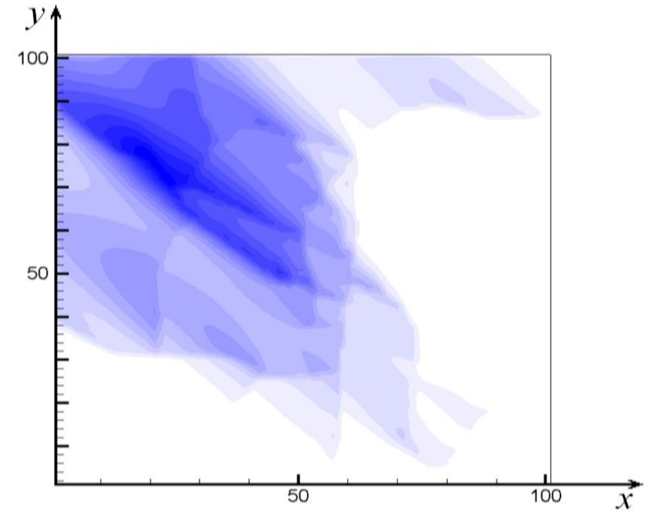

Fig. 4. Expansions from linear source, wind speed is 5 m/s

Figures 3 and 4 represent the results of calculations of harmful contaminants transfer from linear sources on horizontal section. Initial values from linear sources represented in figure 3 (road network of cities) were taken from works [6–8], and Figure 4 provides the results of numerical calculation of the task (2), (5), (6), coincide with the result of the work [7, 8].

In order to simulate the process of harmful impurities dissemination from vehicles in atmospheric air, Web-oriented information system was developed on the basis of probability-statistical model. The system evaluates the level of pollution from vehicles in surface layer of city atmosphere. The results of emissions dissemination are shown in Figure 5.

Fig. 5. Dissemination of emissions from vehicles

3. Conclusion

There are different methods of mathematical modelling of information systems for ecological monitoring of air basin: empiric-statistical method, method of forecasting increased pollution level, method of Gaussian plume model, dynamical-stochastic method.

The basic method chosen in the work is probability-statistical method. It is used for development of the algorithm of numerical modeling of harmful substances transfer process in atmosphere.

Thus, due to turbulent gas flow, it is characteristic that pulsations of speed in all directions are random and chaotic in all points of atmospheric air flow that makes processes be stochastic [8].

The use of probability-statistical modeling for harmful contaminants transfer in atmosphere enables to build up effective numerical algorithms of calculations and considerably reduces amount of calculations, computing time without loss of accuracy.

Information system is based on the model. The developed computer technology enables to display graphically the level of pollution in surface layer of atmosphere on the map of city territory. It also enables to simulate emissions under different traffic conditions and in different regimes of industrial enterprises operation, and to assess the degree of ecological conflict for every condition. Monitoring results can be used for development of routes, traffic schedules of public transport, and operation modes at industrial enterprises where sanitary standards of pollution are observed.

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