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ДЕСЯТАЯ СИБИРСКАЯ КОНФЕРЕНЦИЯ ПО ПАРАЛЛЕЛЬНЫМ И ВЫСОКОПРОИЗВОДИТЕЛЬНЫМ ВЫЧИСЛЕНИЯМ

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Influence of the pollution source location on the concentration of the impurity in street canyon[*]

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The work is devoted to the study of the flow structure and the nature of the impurities distribution in a street canyon, depending on the location of a constant intensity pollution source. The paper considers three cases when the source of the impurity is located: in the center at the bottom of the street canyon, at the bottom under leeward wall and at the bottom under windward wall.

Keywords: *street canyon, mathematical modeling, turbulent flow, impurity concentration.*

This work is devoted to the construction and testing of a mathematical model for studying the processes of transport of impurities in street canyons. Studies of this kind are relevant for understanding the microclimate of cities, are useful in planning new buildings and assessing areas of increased environmental hazard. Based on the developed original micro-scale mathematical model M2U [1], a study was carried out of the influence of the location of the pollution source on the flow structure and the nature of the distribution of impurities inside the street canyon. The mathematical model is based on the Reynolds-averaged Navier-Stokes equations. The system of differential equations is closed using a two-parameter model, which takes into account the influence of buoyancy forces on the turbulent flow structure, and the Boussinesq gradient-diffusion hypothesis. The numerical solution is carried out based on the finite volume method, a monotonized scheme for approximating convective terms, and the SIMPLE algorithm for matching the velocity and pressure fields [2].

In this work, the emphasis is on the study of changes in the maximum and average concentration in the breathing zone of a person (up to 2 m from the ground) and in the canyon as a whole. Three cases of the location of the pollution source were considered: in the center at the bottom of a street canyon, at the bottom at the leeward wall, and at the bottom at the windward wall.

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This study will help to understand how strongly the pollution source location will affect the accumulation of impurities in the street canyon. Thus, the data obtained can be used in the design of residential areas and parking lots.

Physical and mathematical formulation of the problem

Stationary isothermal turbulent air movement in the surface layer over an inhomogeneous underlying surface with elements of large-scale roughness is considered. Roughness elements are fixed, flow-tight obstacles (buildings). A point source of harmful emissions of constant intensity (vehicles) is considered. The dimensions of buildings are commensurate with the dimensions of the study area (Figure 1).

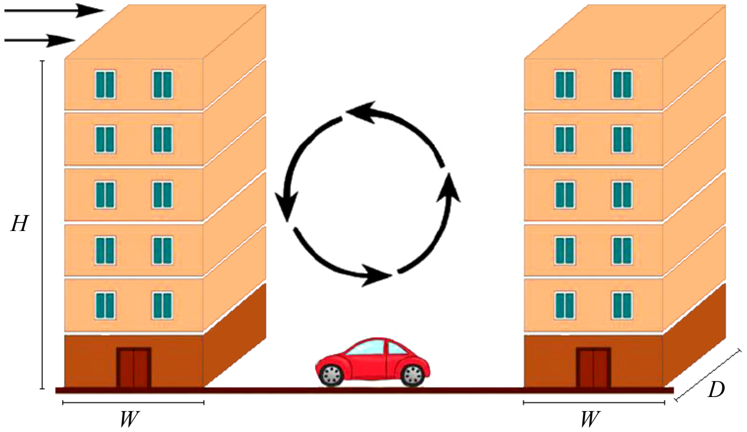

Fig. 1. Physical statement of the problem

The mathematical model includes Reynolds-averaged continuity equations, Navier-Stokes equations, impurity transport [2, 3] and heat transfer:

$$\frac{\partial \bar{u}_i}{\partial x_i} = 0; \qquad (1)$$

$$\frac{\partial \bar{u}_i \bar{u}_j}{\partial x_j} = -\frac{1}{\rho}\frac{\partial \bar{p}}{\partial x_i} + \frac{\partial}{\partial x_j}\left(\nu \frac{\partial \bar{u}_i}{\partial x_j}\right) - \frac{\partial \overline{u'_i u'_j}}{\partial x_j}; \qquad (2)$$

$$\frac{\partial \bar{u}_j \bar{C}}{\partial x_j} = \frac{\partial}{\partial x_j}\left(D \frac{\partial \bar{C}}{\partial x_j}\right) - \frac{\partial \overline{u'_j C'}}{\partial x_j} + \mathrm{S}; \quad i, j = 1, 2, 3. \qquad (3)$$

Here $\overline{u}_i$, u_i' – averaged and ripple projections of the velocity vector on the coordinate axis, $\overline{p}$ – pressure, ρ – density, ν – kinematic viscosity of air, $\overline{C}$ – averaged impurity concentration, S – function describing the distribution of impurity sources, $\overline{u_i'u_j'}$ – Reynolds stress tensor, $D = \nu/Sc$ – diffusion coefficient, Sc – Schmidt number.

The closure of the system of equations (1) – (3) is carried out using the two-parameter «*k*–ε» model and the Boussinesq gradient-diffusion hypothesis [2, 4]:

$$\overline{u_i'u_j'} = -\nu_T\left(\frac{\partial \overline{u}_i}{\partial x_j} + \frac{\partial \overline{u}_j}{\partial x_i}\right) + \frac{2}{3}k\delta_{ij};\quad \overline{C_i'u_j'} = -\frac{\nu_T}{Sc_T}\frac{\partial \overline{C}}{\partial x_j}; \tag{4}$$

$$\nu_T = C_\mu \frac{k^2}{\varepsilon};\quad P = -\overline{u_i'u_j'}\frac{\partial \overline{u}_i}{\partial x_j}; \tag{5}$$

$$\frac{\partial \overline{u}_j k}{\partial x_j} = \frac{\partial}{\partial x_j}\left(\left(\nu + \frac{\nu_T}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right) + P - \varepsilon; \tag{6}$$

$$\frac{\partial \overline{u}_j \varepsilon}{\partial x_j} = \frac{\partial}{\partial x_j}\left(\left(\nu + \frac{\nu_T}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right) + \frac{\varepsilon}{k}\left(C_{\varepsilon 1}P - C_{\varepsilon 2}\varepsilon\right), \tag{7}$$

where ν_T – turbulent viscosity, k – kinetic energy of turbulence, ε – dissipation of turbulent kinetic energy. Turbulence model coefficients: $\sigma_k = 1.0$, $\sigma_\varepsilon = 1.3$, $C_{\varepsilon 1} = 1.44$, $C_{\varepsilon 2} = 1.92$, $C_\mu = 0.09$, $Sc_T = 0.5$ – turbulent Schmidt number.

A full description of the mathematical model used and the numerical method for its solution is given in [5].

Simulation of flow and parametric calculations

The analysis of the influence of the location of the pollution source in the street canyon on the maximum concentration of the impurity in the breathing zone (up to 2 m from the bottom of the canyon) and in the canyon as a whole is carried out. The geometric characteristics of the street canyon are: height (*H*) and width (*W*) 20 meters, depth (*L*) – 30 meters. The calculations were carried out on a structured Cartesian grid 110 62 100 along the axes *Ox*, *Oy* and *Oz*, respectively. The mesh was compacted at the border nodes. The size of 5 border cells in the direction normal to the solid boundary was 0,1 m. This is done to get the dimensionless y+ into the recommended range of 30 to 300.

The source of constant-intensity admixture was located in the center, at the leeward wall and at the windward wall of the street canyon, near the bottom.

The viscosity of the medium is considered to be $\nu = 15 \cdot 10^{-6}$ m^2/s, which corresponds to the viscosity of the air at 20 °C. The boundary conditions were set as follows: at the inlet boundary, the horizontal velocity $U_{in} = 1$ m/s; at the outlet boundary, the normal velocity derivatives are equal to zero; no-slip conditions were considered on the generators of the street canyon and on the roofs of buildings; sliding conditions are set on the upper wall. Initial conditions: the longitudinal velocity is equal to the inlet velocity (1 m/s), and the vertical velocity and pressure are zero.

As can be seen from the vector velocity fields (Figure 2), the wind flow passing over the canyon affects the air masses inside the canyon, setting them in motion. Thus, one large vortex is formed within the canyon, which, in turn, acts on the source of the impurity, setting the impurity in motion. Thus, the weathering process begins.

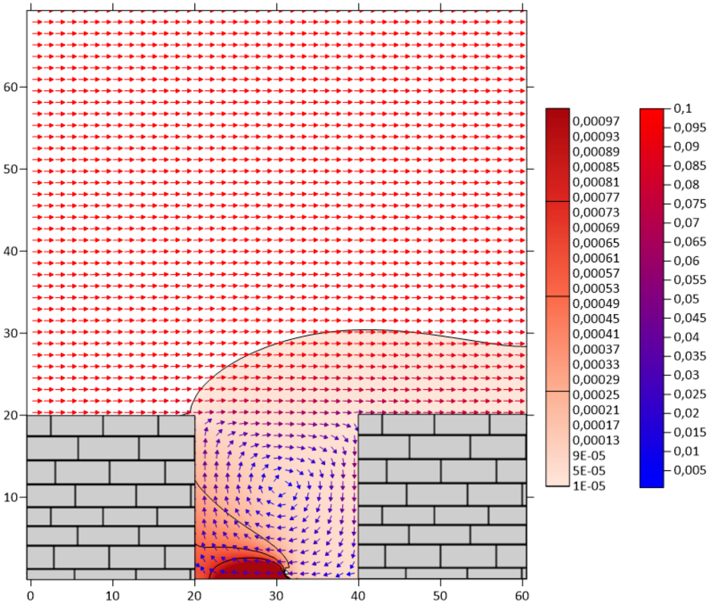

Fig. 2. Vector velocity field and the contour fields of concentration with center location of the pollution source. The width, height and depth of the street canyon are 20 m, 20 m and 30 m, respectively

As a result of modeling the transport of impurities in a street canyon, the following pictures of the distribution of its concentration were obtained (Figure 2, 3).

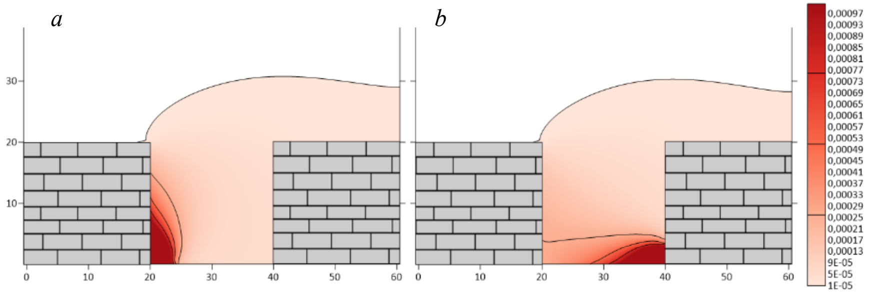

Figure 3. Contour fields of concentration in a street canyon with
a) left and *b*) right locations of the pollution source

In all three cases, the admixture is weathering from the canyon. When the source is displaced to any of the street canyon generators, the deterioration of the admixture weathering is observed. This fact is confirmed by the following integral characteristics of the maximum concentrations of impurities in the breathing zone (Table).

Maximum impurity concentrations in the breathing zone

Source location	Left	Middle	Right
C	1,919602	0,15369	0,51267

The maximum impurity concentrations in case of left source location are several times higher than the maximum impurity concentrations in the case of right location, which is explained by poor ventilation, which depends on the velocity and direction of the wind. In case of central source location, the impurity does not have time to accumulate and is well weathered.

Conclusion

A microscale model of turbulent air movement and impurity transport in a street canyon is presented. For isothermal turbulent air flow in the canyon, it was investigated how different variants of the location of the pollution source affect the accumulation of the incoming admixture inside the street canyon (Figure 2, 3). The integral characteristics of the impurity concentration in the street canyon in general and in the breathing zone (up to 2 m from the bottom of the canyon) are calculated and analyzed.

The location of the source of the impurity directly depends on how the impurity will accumulate in the street canyon. The case of the central source location showed the best weathering of the admixture, the left is the worst.

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