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The proceedings of the 25th International Scientific Conference Transport Means 2021 contain selected papers of 9 topics: Aviation, Automotive, Defence Technologies, Fuels and Combustion, Intelligent Transport Systems, Railway, Traffic, Transport Infrastructure and Logistics, Waterborne Transport.

All published papers are peer reviewed.

The style and language of authors were not corrected. Only minor editorial corrections may have been carried out by the publisher.

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PREFACE

25th international scientific conference TRANSPORT MEANS 2021 due to the COVID-19 pandemic in the world, for the second time was organized as a virtual event on 06-08 October, 2021. It continues long tradition and reflects the most relevant scientific and practical problems of transport engineering.

The conference aims to provide a platform for discussion, interactions and exchange between researchers, scientists and engineers.

The reports cover a vide variety of topics related to the most pressing issues of today's transport systems development.

The main areas covered in plenary session and in the sections are: design development, maintenance and exploitation of transport means, implementation of advanced transport technologies, development of defense transport, environmental and social impact, advanced and intelligent transport systems, transport demand management, traffic control, specifics of transport infrastructure, safety and pollution problems, integrated and sustainable transport, modeling and simulation of transport systems and elements.

In the invitations to the conference, sent five months before the conference starts, the instructions how to prepare reports and how to model the manuscripts are provided as well as the deadlines for the reports are indicated.

Those who wish to participate in the conference should send the texts of the reports that meet relevant requirements under indicated deadlines. Each report must include: a short description of the idea or technique being presented, a brief introduction orienting to the importance an uniqueness of the submission, a thorough description of research course and comments on the results.

The submissions are matched to the expertise according to the interests and are forwarded to the selected reviewers.

Scientific Editorial Committee revises, groups the properly prepared reports according to the theme and design the conference programme.

The Proceedings are compendium of selected reports presented at the Conference.

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Prof. V. Ostaševičius

Proceedings of 25th International Scientific Conference. Transport Means 2021.

Road with Fan for Reducing Exposure to Traffic Emissions

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Abstract

In this paper, a numerical model is proposed for calculating pollution zones near the road, where axial exhaust fans are locally installed at the height of protective barriers, which ensure the intake of emissions from vehicles. The basis of the mathematical model is the equation of convective-diffusion transfer of impurities, which takes into account the intensity of emissions from cars, the unevenness of the air flow, atmospheric diffusion. The calculation of the wind flow velocity field in the presence of cars, an axial fan and a protective screen on the road is carried out on the model of a vortex-free flow of an ideal fluid. For the numerical integration of the mass transfer equation, implicit difference splitting schemes are used. For the numerical solution of the aerodynamic equation, a conditional approximation difference scheme is used. A computer code has been developed that implements the constructed numerical model. The results of computational experiments to assess the effectiveness of axial fans to reduce the level of gas pollution near highways are presented. Scenarios considered: axial fan and protective barrier; additional screen on the barrier; axial fan and two protective barriers
KEY WORDS: *noise barrier, axial fan near road, numerical simulation, air pollution*

1. Introduction

Currently, there is a steady upward trend in the number of vehicles. The development of transport, construction and maintenance of transport infrastructure increases the burden on the environment and people due to air pollution. Air pollutants, such as carbon monoxide, nitrogen oxides, hydrocarbons or lead, accumulate near sources of pollution, along the road, on the street, in tunnels, at intersections. During the construction and reconstruction of the city districts, technological solutions are needed to reduce the level of harmful substances during the idle operation of the car engine at the stop. Emissions from cars on highways significantly affect the quality of the air.

There are two important tasks within this problem. The first task is to predict the level of air pollution near the highway. The second problem is to minimize the level of air pollution near the highway.

To minimize the level of pollution at the working areas near highways, a number of tools are used, for example [1-5]: the use of vegetation; installation of protective barriers [8-9]; the use of suction devices near the track; the use of special solutions for dust suppression on the highway; the use of a special coating that "neutralizes" the impurity; the use of axial fans located at a certain height from the highway.

For the practical use of a specific means to protect air from pollution near highways, a scientific justification of its effectiveness is needed at the stage of creating a project. Conducting physical experiments to solve this important task requires considerable time to set up and conduct the experiment. Therefore, it is important to have specialized mathematical models that allow to assess quickly the effectiveness of a particular method of protection at the stage of development of a project to protect air from pollution near the highway. This paper considers the construction of a numerical model for the analysis of axial fans efficiency while reducing the level of air pollution near the highway.

2. Statement of the Problem and Its Solution

2.1. Mathematical Model

A city-wide highway with continuous three-lane traffic is considered, the width of one lane is 3.75 m, on one side of the road there are protective screens (barriers) with an axial fan installed at the location of the traffic light, because there is the highest level of *CO* during idle operation of vehicles (Fig. 1). The task is to calculate the zone of air pollution during the emission of pollutants from vehicles, as well as to assess the impact of the axial fan on reducing the concentration of harmful substances behind the screen. Exhaust of polluted air that got into the selection system can be carried out through ventilation pipes by supplying polluted air to the cleaning system [9].

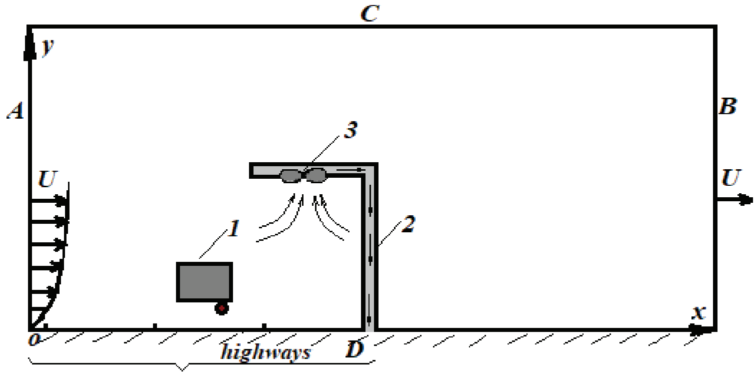


Fig. 1 The scheme of axial fan usage together with a protective barrier: *1* – the car; *2* – protective barrier; *3* – axial fan; *A*, *B*, *C*, *D* – boundaries of the calculated domain

The following equations are used to estimate the level of air pollution near the highway, where the protective barrier with an axial fan is located (Fig. 1) [2, 7]:

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

$$\frac{\partial^2 P}{\partial x^2}+\frac{\partial^2 P}{\partial y^2}=0; \tag{2}$$

$$u=\frac{\partial P}{\partial x};\ v=\frac{\partial P}{\partial y}. \tag{3}$$

where C – the concentration of impurities in the air, [kg/m3]; μ_x, μ_y – turbulent diffusion coefficients, [m^2/s]; u, v – components of the air flow velocity vector, [m/s]; Q_i – impurity emission intensity [kg/(s·m^3)]; $\delta(x-x_i)\delta(y-y_i)$ – delta Dirac function; (x_i, y_i) – coordinates of pollutant sources, [m]; P – speed potential; t – time, [s].

The following boundary conditions are set for solving the system of equations Eq. (1) – Eq. (3) – (Fig. 1):

1. $C=C_{entrance}$ or $C=0$; $\left.\frac{\partial P}{\partial x}\right|_A=U$ – at the boundary of the inlet of stream *A*, where U – the known flow speed;
2. $\left.\frac{\partial C}{\partial x}\right|_B=0$; $P=\text{const}$ – at the boundary *B* "exit" of the flow;
3. $\left.\frac{\partial C}{\partial y}\right|_{C,D}=0$; $\left.\frac{\partial P}{\partial y}\right|_{C,D}=0$ – at the impenetrable boundaries *C*, *D*;
4. On all solid walls, taking into account the screen, the body of the car is a condition of impermeability for both concentration and speed potential, depending on the direction of the normal to the surface.

For the moment of time $t=0$, the initial condition is written as follows $C_{t=0}=0$.

The Eq. (1) is used to calculate the impurity concentration field near the highway. Eq. (2) is used together with relations (3) to calculate the air velocity field near the highway, where the protective barrier with the axial fan is located.

2.2. Numerical Model

Consider the methodology for constructing a numerical model based on the equations Eq. (1) – Eq. (2). Numerical integration of modeling equations is carried out on a rectangular difference grid $(x, y)_{i,j}=(i\cdot\Delta x, j\cdot\Delta y)$, $i, j\in Z$. For numerical integration of the equation Eq. (1) two different schemes are used. Splitting the equation Eq. (1) at the differential level is carried out as follows:

$$\frac{\partial C}{\partial t}+\frac{\partial uC}{\partial x}+\frac{\partial vC}{\partial y}=0; \tag{4}$$

$$\frac{\partial C}{\partial t}=\frac{\partial}{\partial x}\left(\mu_x\frac{\partial C}{\partial x}\right)+\frac{\partial}{\partial y}\left(\mu_y\frac{\partial C}{\partial y}\right); \tag{5}$$

$$\frac{\partial C}{\partial t}=\sum Q_i\cdot\delta\left(x-x_i\right)\cdot\delta\left(y-y_i\right). \tag{6}$$

Further, the following transformations and approximations of derivatives are performed [2, 7]:

$$\frac{\partial uC}{\partial x}=\frac{\partial u^+C}{\partial x}+\frac{\partial u^-C}{\partial x};\ \frac{\partial vC}{\partial y}=\frac{\partial v^+C}{\partial y}+\frac{\partial v^-C}{\partial y}; \tag{7}$$

$$u^+=\frac{u+|u|}{2};\ u^-=\frac{u-|u|}{2};\ v^+=\frac{v+|v|}{2};\ v^-=\frac{v-|v|}{2}. \tag{8}$$

$$\frac{\partial u^+C}{\partial x}\approx\frac{u^+_{i+1,j}C^{n+1}_{i,j}-u^+_{i,j}C^{n+1}_{i-1,j}}{\Delta x}=L^+_xC^{n+1};\ \frac{\partial u^-C}{\partial x}\approx\frac{u^-_{i+1,j}C^{n+1}_{i+1,j}-u^-_{i,j}C^{n+1}_{i,j}}{\Delta x}=L^-_xC^{n+1} \tag{9}$$

$$\frac{\partial v^+C}{\partial y}\approx\frac{v^+_{i,j+1}C^{n+1}{}_{i,j}-v^+_{i,j}C^{n+1}{}_{i,j-1}}{\Delta y}=L^+_yC^{n+1};\frac{\partial v^-C}{\partial y}\approx\frac{v^-_{i,j+1}C^{n+1}{}_{i,j+1}-v^-_{i,j}C^{n+1}{}_{i,j}}{\Delta y}=L^-_yC^{n+1}; \tag{10}$$

$$\frac{\partial}{\partial x}\left(\mu_x\frac{\partial C}{\partial x}\right)\approx\mu_x\frac{C^{n+1}_{i+1,j}-C^{n+1}_{ij}}{\Delta x^2}-\mu_x\frac{C^{n+1}_{ij}-C^{n+1}_{i-1,j}}{\Delta x^2}=M^-_{xx}C^{n+1}+M^+_{xx}C^{n+1}; \tag{11}$$

$$\frac{\partial}{\partial y}\left(\mu_y\frac{\partial C}{\partial y}\right)\approx\mu_y\frac{C^{n+1}_{i,j+1}-C^{n+1}_{ij}}{\Delta y^2}-\mu_y\frac{C^{n+1}_{ij}-C^{n+1}_{i,j-1}}{\Delta x^2}=M^-_{yy}C^{n+1}+M^+_{yy}C^{n+1}. \tag{12}$$

For Eq. (4) the following splitting scheme is used:

– first step, $\dfrac{C^k_{i,j}-C^n_{i,j}}{\Delta t}+L^+{}_xC^k+L^+{}_yC^k=0$;

– the second step, $\dfrac{C^{n+\frac{3}{4}}_{i,j}-C^{n+\frac{1}{2}}_{i,j}}{\Delta t}+L^-{}_xC^{n+\frac{3}{4}}+L^-{}_yC^{n+\frac{3}{4}}=0$.

For numerical integration of Eq. (5) two-step splitting scheme is used:

$$\frac{C^{n+\frac{3}{4}}_{i,j}-C^{n+\frac{1}{2}}_{i,j}}{\Delta t}=0.5\cdot\left(L^-{}_{xx}C^{n+\frac{1}{2}}+L^+_{xx}C^{n+\frac{3}{4}}+M^-{}_{yy}C^{n+\frac{1}{2}}+M^+{}_{yy}C^{n+\frac{3}{4}}\right); \tag{13}$$

$$\frac{C^{n+1}_{i,j}-C^{n+\frac{3}{4}}_{i,j}}{\Delta t}=0.5\cdot\left(L^-{}_{xx}C^{n+1}+L^+_{xx}C^{n+\frac{3}{4}}+M^-{}_{yy}C^{n+1}+M^+{}_{yy}C^{n+\frac{3}{4}}\right); \tag{14}$$

Numerical integration of Eq. (6) is carried out by the method of Euler [2, 6]:

$$C^{n+1}_{ij}=C^n_{ij}+\Delta t\sum Q_i\cdot\delta\left(x-x_i\right)\delta\left(y-y_i\right)/\Delta x/\Delta y; \tag{15}$$

For numerical integration of the equation an explicit finite-difference scheme of numerical integration is used. Laplace Eq. (2) reduces to an equation of the evolutionary type:

$$\frac{\partial P}{\partial\eta}=\frac{\partial^2P}{\partial^2x}+\frac{\partial^2P}{\partial^2y}, \tag{16}$$

where η is the dummy time, when $\eta\to\infty$, the solution of equation (16) goes to the solution of Laplace Eq. (2). To solve this equation it is necessary to specify the initial condition, the potential field at $\eta=0$. For example, you can take $P_{\eta=0}=0$ to the entire calculation area.

Based on the method of numerical integration [2, 6], the calculated dependence for solving Eq. (16) has the form:

$$P_{ij}^{n+1} = P_{ij}^{n} + \Delta t \frac{P_{i+1,j}^{n} - 2P_{ij}^{n} + P_{i-1,j}^{n}}{\Delta x^2} + \Delta t \frac{P_{i,j+1}^{n} - 2P_{ij}^{n} + P_{i,j-1}^{n}}{\Delta y^2}, \quad (17)$$

With the help of this explicit dependence, the velocity potential field in all internal cells of the computational domain is determined. The calculation of the velocity potential ends when the condition: $\left|P_{ij}^{m+1} - P_{ij}^{m}\right| \le \varepsilon$, where ε – a small number ($\varepsilon = 0.001$); m – iteration number.

The value of the velocity potential is determined in the centers of the difference cells, the value of the components of the velocity vector is calculated on the sides of the difference cells:

$$u_{ij} = \frac{P_{ij} - P_{i-1,j}}{\Delta x}; \; v_{ij} = \frac{P_{ij} - P_{i,j-1}}{\Delta y}. \quad (18)$$

2.3. Results of Computational Experiments

Based on this numerical model, the code "SCREEN-2A" was created in the FORTRAN programming language, which was used to solve the problem of assessing the level of pollution near the road in the presence of emission source (vehicles), with the location of screens and axial fan.

Various scenarios for the location of vehicles, screens and axial fan were considered. The calculations were performed with the following data: air flow speed 1.7 m/s and 6 m/s, the average intensity of carbon monoxide emissions from vehicles – 0,02 g/(s· m), the geometric dimensions of the area – 12 m along the axis *Ox* and 10 m along the axis of *Oy*, which is directed vertically upward. The coordinates of the *CO* emission source are the coordinates of the exhaust pipe of the car. It is assumed that this is a point source of emission, so in the mathematical model it is given by the delta Dirac function δ_{ij}, and in the numerical model – the position of the difference cell in which the emission source is located, namely $Q_{numerical} = Q(t)_{source} / (\Delta x \Delta y)$, where $Q(t)_{source}$, is the actual *CO* emission from the car [g/(s· m)], $\Delta x \Delta y$ – the area of the difference cell. The highway is modeled as a set of point sources. Since the two-dimensional model is used, the wind direction is chosen perpendicular to the highway (along the axis *Ox*). The model problem is solved taking into account the action of the screen as a barrier, cars with dimensions were considered as vehicles: width – 1,7 m, height – 1,6 m, but the calculation program allows to take into account any size of vehicles; turbulent diffusion coefficient 2 m^2/s; height of the protective barrier 5 m; air suction speed at the fan inlet 12 m/s.

The effectiveness of reducing air pollution near the highway was studied in the following scenarios:

– barrier + axial fan (scenario 1, Fig. 1);
– barrier + axial fan + additional screen on the barrier (scenario 2, Fig. 2);
– barrier + axial fan + barrier on the other side of the highway (scenario 3, Fig. 3).

Based on the calculations, the following results were obtained. Figure 4 shows the distribution of the *CO* concentration field for two values of wind speed 1.7 m/s (Fig. 4a) and 6 m/s (Fig. 4b). In these figures, each number shows the concentration as a percentage of its maximum value in the calculation area. It can be seen that the efficiency of the fan decreases with increasing wind speed due to the fact that at higher wind speeds there is a "wear" of the plume of pollution from the fan. The level of *CO* concentration behind the barrier is higher at a wind speed of 6 m/s than at 1.7 m/s by 3-5 %.

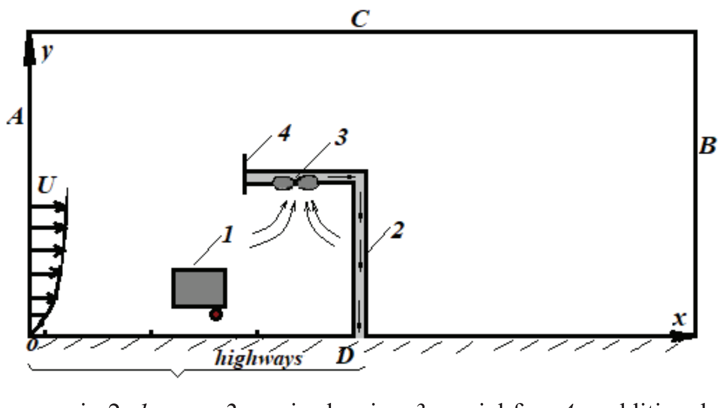


Fig. 2 Calculation scheme, scenario 2: *1* – car; *2* – noise barrier; *3* – axial fan; *4* – additional screen on the barrier; *A*, *B*, *C*, *D* – boundaries of the calculated domain

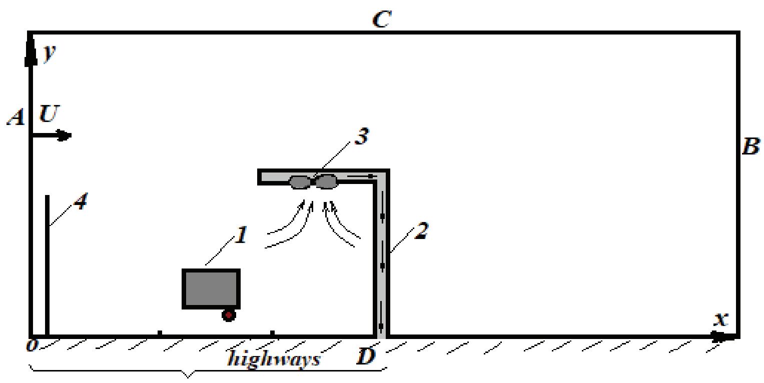
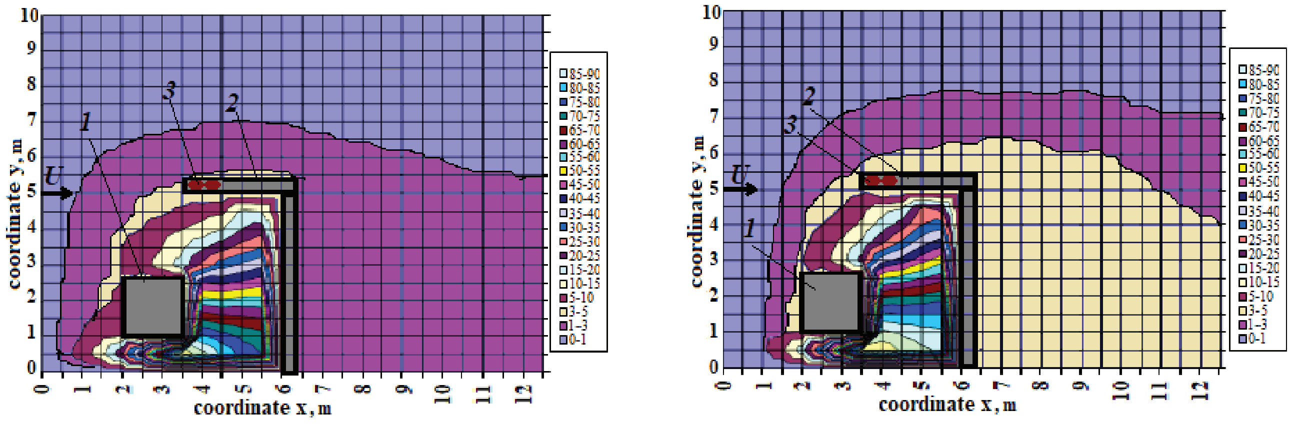


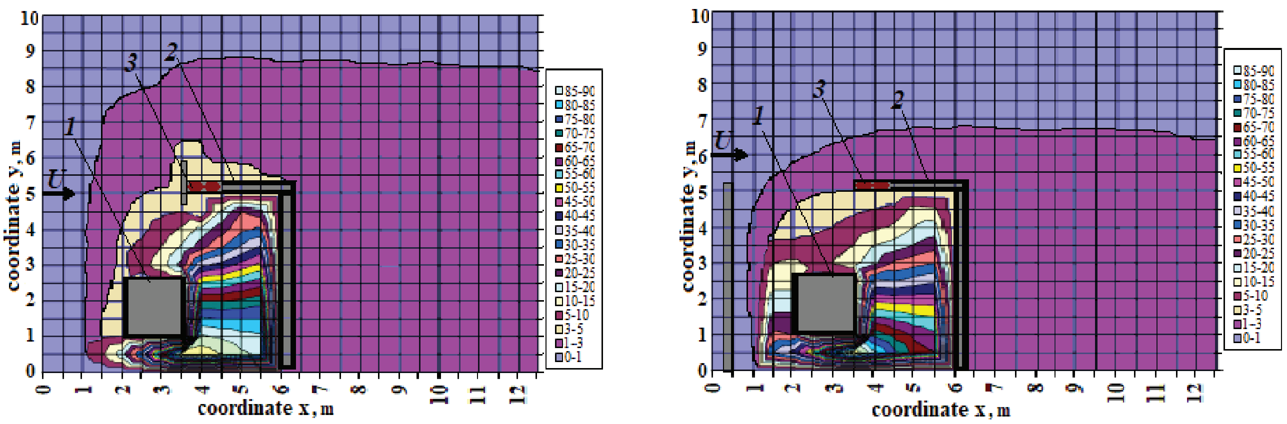
Fig. 3 Calculation scheme, scenario 3: *1* – car; *2* – noise barrier; 3 – axial fan; *4* – barrier on the left side of the highway; *A*, *B*, *C*, *D* – boundaries of the calculated domain



a b

Fig. 4 Field of *CO* concentration, scenario 1: *1* – car, *2* – barrier, *3* – axial fan (C_{CO} as a percentage of $C_{CO\max}$), where a – wind speed of 1.7 m/s, $C_{CO\max}$ = 7.6869 mg/m^3; b – wind speed of 6 m/s, $C_{CO\max}$ = 5.2694 mg/m^3

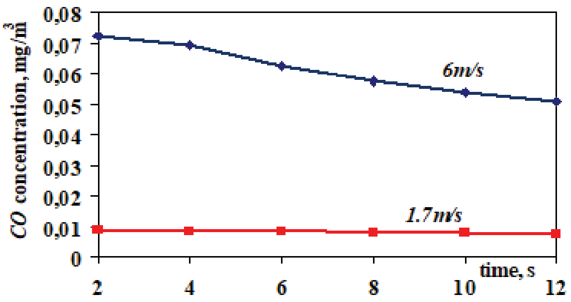
In Fig. 5, a shows the distribution of the *CO* concentration field at a wind speed of 6 m s in the presence of an additional screen on the barrier (scenario 2, Fig. 2). In Fig. 5, b shows the distribution of the *CO* concentration field at a wind speed of 6 m/s in the presence of a barrier on the other side of the highway (scenario 3, Fig. 3). The presence of an additional screen on the barrier (Fig. 5, a) allows to change the geometry of the flow and direct it to a greater height, thereby, due to diffusion to reduce the level of pollutant concentration behind the barrier. The usage of barrier on the other side of the road as an additional obstacle to the wind flow reduces the "wear" of the plume of pollution from the fan, thereby facilitating its localization near the fan and more efficient *CO* selection.



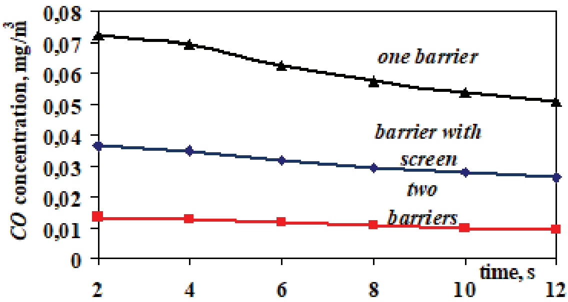
a b

Fig. 5 Field of *CO* concentration, scenario 2 and scenario 3: *1* – car, *2* – barrier, *3* – axial fan (C_{CO} as a percentage of $C_{CO\max}$), where a – wind speed 6 m/s, $C_{CO\max}$ = 5.1068 mg/m^3 for barrier with screen b – wind speed of 6 m/s, $C_{CO\max}$ = 9.6927 mg/m^3 two barriers

Fig. 6, a shows the change of *CO* concentration behind the barrier at a height of 1.7 m with time at a wind speed of 1.7 m/s and 6 m/s for scenario 1. It can be seen that the axial fan for large values of wind speed 6 m/s works less efficiently, so additional technological means are needed to reduce the level of pollution and at such wind speeds. It has been proposed to use an additional screen on the barrier (scenario 2), it reduces the wind speed near the fan, redirects the flow in height, which reduces the concentration value behind the barrier by 50%. At the next stage of the study, calculations were made taking into account the establishment of the second barrier on the opposite side of the road (scenario 3), which leads to a decrease in concentration by 80% behind the first barrier, but the maximum level of concentration on the road is much higher than in previous cases, which is harmful to drivers and passengers who are in the cabin during traffic lights on city roads.



a



b

Fig. 6 Change in *CO* concentration along the barrier at a height of 1.7 m over time: a – scenario 1, wind speed 1.7 m/s and 6 m/s; b – scenarios 1, 2, 3 for a wind speed of 6 m/s

It can be seen from Fig. 6, b that in scenario 3 the most effective reduction of the impurity concentration behind the barrier takes place. The calculation time of one scenario is 5 s.

3. Conclusions

A numerical model has been developed to determine the effectiveness of reducing air pollution using protective barriers on which an axial fan is installed.

The model is based on the mass transfer equation and the equation for the velocity potential.

A feature of the model is the possibility to take into account the complex geometric shape of the barrier.

The results of computational experiments conducted on the basis of a split numerical model show that with increasing wind speed, the efficiency of the fan decreases.

It is possible to increase the efficiency of this tool by using an additional screen on the protective barrier and an additional barrier on the opposite side of the road.

Refereces

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Author’s Index

Contents

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