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APPLICATION OF LOCAL EXHAUST SYSTEMS TO REDUCE POLLUTION CONCENTRATION NEAR THE ROAD

Summary. In this study, the methodological foundations of the technology for the local reduction of chemical pollution from vehicles were improved through the use of two-level suction units and guide plates of various lengths installed on the nozzles of the suction devices. A program has been developed for the numerical calculation of the carbon monoxide concentration field for evaluating the efficiency of using two-level exhaust systems with different lengths of guide plates on the gas flow selection pipes. The solution of the equations of hydrodynamics and mass transfer is carried out on the basis of finite-difference methods. A number of physical and computational experiments have been carried out; it has been established that the concentration of carbon monoxide in the zone of two-level suctions location decreases by 46-68%.

1. INTRODUCTION

At present, air pollution by vehicles remains an urgent problem. The concentration of harmful substances is localized at low altitudes, both on long and saturated motorways and on highways in residential areas of the city. In the first case, this is owing to high speeds of vehicles of 160-200 km/h and the process of incomplete combustion of fuel, and in the second case, the idling of vehicles in the area of intersections and traffic lights, which leads to a large accumulation of harmful substances. Air pollution is one of the main risk factors for human health. The lower the level of air pollution is, the less cases of cardiovascular, respiratory, and cancer diseases occur. Successful policies to reduce urban air pollution are driven by the reengineering of transport networks and urban planning [1-2].

A modern highway is a complex engineering structure that is a powerful source of man-made impact on the environment. The emission of pollutants on the highway is a particular threat to humans. The issues of protecting the atmosphere from pollution by vehicle emissions should be considered in a comprehensive manner, together with other issues at the design (reconstruction) stage of the road. The purpose of the applied methods of protection is to limit the spread of pollutants to the human respiratory system.

It should be noted that the existing methods to reduce the negative effect of emissions on the highway can be divided into two main groups. The first group includes methods aimed at the source of the emission itself, i.e. on the car. For example, there are different methods: improving car engines; improving their technical condition; installing a liquid catalyst in the exhaust system, which ensures the processes of capturing, chemical binding, and neutralizing toxic components and soot particles [3-4]; the usage of new types of fuel; keeping the car in good condition; rational organization of transportation routes and traffic; the use of more wear-resistant tires; improvement of braking devices; and decrease in traffic intensity. Obviously, the listed measures have a common feature – it is a decrease in the intensity of emissions from an emission source on the road, and therefore a decrease of environmental pollution level.

The second group of methods is aimed at the road itself. It is known that during the construction of the road, a set of tasks is carried out to reduce its negative effect on the environment. This group of methods aimed at protecting atmospheric air from pollution near the road include the following: planting vegetation [5-10]; installing barriers (screens) near highways [10-11]; the usage of axial fans on barriers; the usage of special coatings on the road [12-14]; removal of polluted air from the road surface (usage of local exhaust devices on the road) [10]; and usage of underground tunnels to unload transport routes.

It should be noted that each method of protecting the air environment near the road has its own advantages and disadvantages. However, no matter what method of engineering protection would be chosen, the most important task is to assess its effectiveness at the design or reengineering stage of the highway. In particular, the usage of local exhaust devices, which is the subject of this article, should only be used in areas with a significant concentration of polluted air, for example, busy urban intersections, tunnels, or windproof sections of a motorway with a special terrain profile, where an increased concentration of emissions is possible.

When making design decisions, it is necessary to have special calculation methods to assess the effectiveness of using protection methods for a specific road section. Currently, to assess the level of air pollution, the Gaussian model is widely used, which is implemented in the form of specialized software packages (AERMOD, etc.). This model provides important predictive data quickly but cannot be used for uneven air velocity field and also if sound barriers are used near the road or there are local exhaust systems for polluted air. Therefore, an urgent issue is the development of methods for the numerical calculation of the air pollution concentration, as well as the creation of a software package for carrying out the required number of numerical experiments in order to obtain an objective assessment of two-level exhaust systems.

Reducing the level of chemical pollution near highways is quite difficult from the point of aerodynamics and mass transfer, as it requires determining the velocity and concentration field not only in a certain area but also in the entire area at each moment of time. The solution of this task is possible by numerical methods, as a rule, on the basis of developed software packages [15-20].

The connection between a person near the road and the negative health effects is significant. Such studies can be carried out not only on the basis of statistical data, which provide the number of people who have the same modeling methods based on numerical calculation processes for analyzing the field of pollutants. Local exhaust systems can clean from 40% to 75% of all harmful substances, and their level in the respiratory system is significantly reduced.

2. STATEMENT OF THE RESEARCH PROBLEM

The object of the study is to reduce the concentration of gas emissions from vehicles on the road sections where traffic lights are located, through the use of two-level exhaust systems. Idling of the engine leads to the most intense intake of pollutants into the air; therefore, it is advisable to install exhaust systems in these places of the city. As a rule, the intake of polluted air is carried out using one suction port; however, the suction speed drops sharply even at a small distance from the port.

When using one hole for air intake, the capture area of contaminated particles is small enough, and particles of contaminated air do not get into the hole, begin to move upward, flowing around the obstacle. Therefore, it is rational to place an additional hole to suck in the polluted air that remains in the space. The removal of contaminated air that has entered the suction can be carried out through the ventilation pipes in two ways: the first is the supply of contaminated air to the purification system [10], Fig. 1*a*, but this leads to an increase in the cost of equipment, and the second is the emission of polluted air through the pipe to a great height from the surface of the earth, Fig. 1*b*, where the wind speed is higher, which means that the dispersion is more intense. The paper proposes the usage of two-level exhaust system with an adjustable distance between the nozzles and the outlet of polluted air according to Fig. 1*b*.

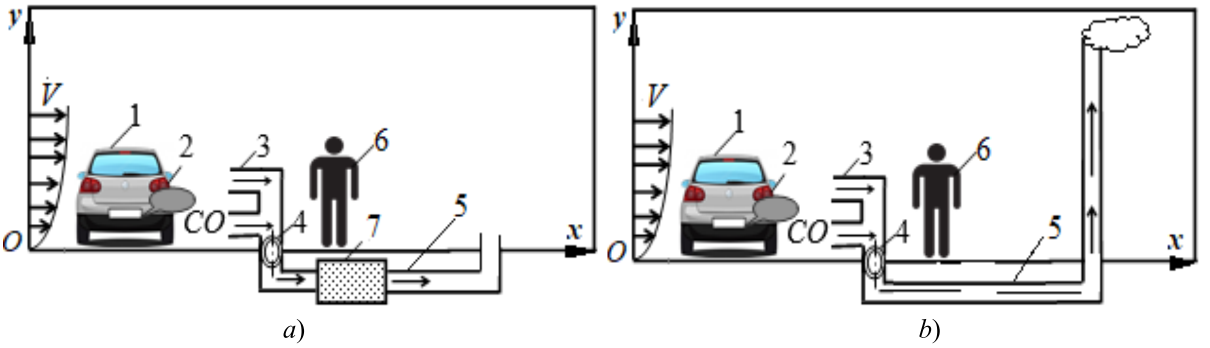


Fig. 1. Scheme of selection and removal of exhaust gases: *a* – outlet to the cleaning system; *b* – branch to a great height. 1 – motor vehicles, 2 – emission source, 3 – gas extraction pipes (nozzles), 4 – fan, 5 – gas outlet; 6 – a person in the area of the pollution source, and 7 – a cleaning system

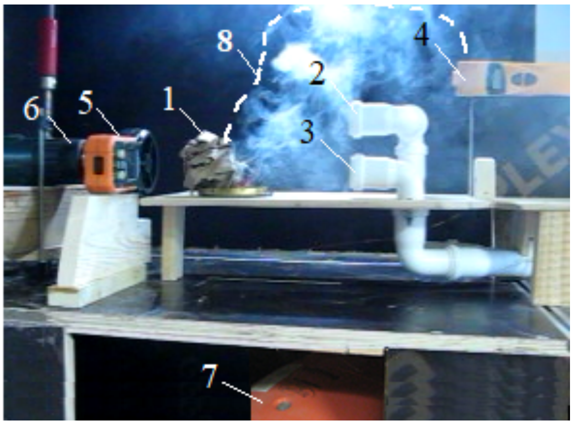
3. EXPERIMENTAL STUDIES

In this work, experimental studies were continued to assess the effectiveness of the use of exhaust devices located near the road. The first results in this area were presented in the studies by Biliaiev, M.M. and Rusakova, T [21-22]. Different scenarios were considered when on the nozzles of the suction devices there were no additional elements – guide plates (Fig. 2*b*), or they were installed of the same length (Fig. 2*c*, position 9). The experimental setup is shown in Fig. 2*a*, where 1 is an emission source; 2 and 3 – holes for gas sampling; 4 – device for measuring CO concentration (analyzer Carbon Monoxide Meter Model: 7701); 5 – device for measuring the speed of the incoming flow (anemometer PM 6252 B Digital Anemometer); 6 – pressure fan, 7 – exhaust fan; 8 – polluted zone; and 9 – guide plates, which are additional elements for changing the aerodynamics of the flow near the exhaust system. The choice of the sizes of these additional elements is justified by calculating the pollution zones for a specific section of the road using the developed numerical model. In the experiment, the plates were made of plastic, and their dimensions were as follows: length l=3 cm, width b=3 cm, and height h=0.5 cm. Laboratory studies were carried out in the laboratory of the Department «Hydraulics and Water Supply» of Dnepropetrovsk National University of Railway Transport named after Academician V. Lazaryan. The scale of the experimental setup was 1:10, the Reynolds number corresponded to the turbulent regime, the oncoming flow velocity was taken as the characteristic velocity, and measurements were carried out at an air flow temperature of 23ºC. Plastic cylindrical billets 10-cm long and 0.5 cm in diameter were used as the emission source. The measurements were carried out when the *CO* concentration from the emission source reached a steady state. The purpose of the experiments was to study the size of the polluted zone in the absence of sampling and during the operation of a two-level exhaust system without horizontal guide plates, and taking into account their influence. High-speed video filming was used to record the polluted zone.

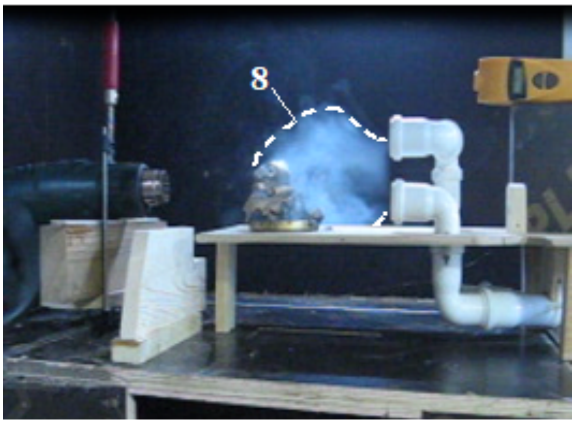
Comparing the results of the experiments presented in Fig. 2*a*-*c*, it can be seen that the use of a two-level exhaust system without guide plates (Fig. 2*a*) makes it possible to reduce the size of the polluted zone – the value of the carbon monoxide concentration decreases by 30-40%.

The presence of guide plates of the same length (Fig. 2*b*) localizes the pollution zone and significantly reduces it in size. During the time t=14 s, the pollution contained in the air above the second hole has already been taken away by the upper hole. The lower hole continues to select contaminants most actively, where the concentration decreases to 14 ppm, in contrast to the case when horizontal plates were absent C=23 ppm with the same observation time. The lower hole catches impurities faster, and the plates slow down the flow, thereby keeping it at the level of the exhaust system holes, ensuring better suction.

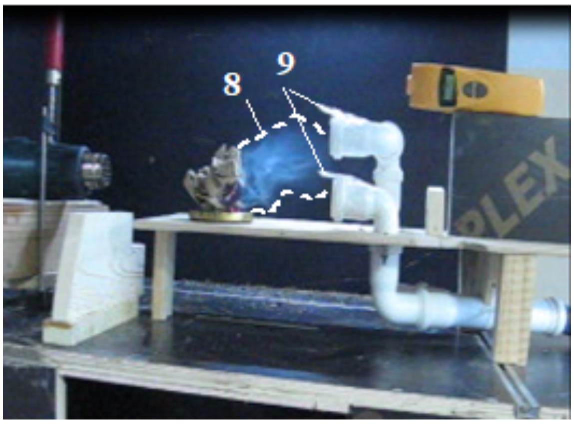
At the next stage of research, a working hypothesis was formulated that the installation of guide plates of different lengths, the upper one of which is longer, will lead to a more significant reduction in the contamination zone. A horizontal plate with a length of l=6 cm was installed on top of the upper hole of the exhaust system, and on the lower hole with a length of l=3 cm (Fig. 3, position 9). The reaching of device indications in terms of concentration is approximately the same as in previous experiments C=70-75 ppm without the operation of the suction; then, the exhaust fan is turned on, and the gas sampling rates at the lower and upper openings are equal to V_{ap}=3.3 m/s and V_l=2.25 m/s, respectively. It is clearly seen how vortices descend from the end of the upper plate to avoid infinite velocity according to the Chaplygin-Zhukovsky postulate and form vortex bunches. Despite this effect, the concentration in the contaminated zone decreases, and at the time t=4 s, the concentration was C=28 ppm (Fig. 3*a*), whereas in the first situation, when there were no plates, the concentration of carbon monoxide was C=42 ppm, and in the second situation, when horizontal plates of the same length were used, C=38 ppm.



a)



b)



c)

Fig. 2. Formation of the polluted zone: *a* – the exhaust fan does not work; *b* – the exhaust fan operates without guide plates t=14 s; *c* – the exhaust fan operates with the same guide plates t=14 s [21-22]

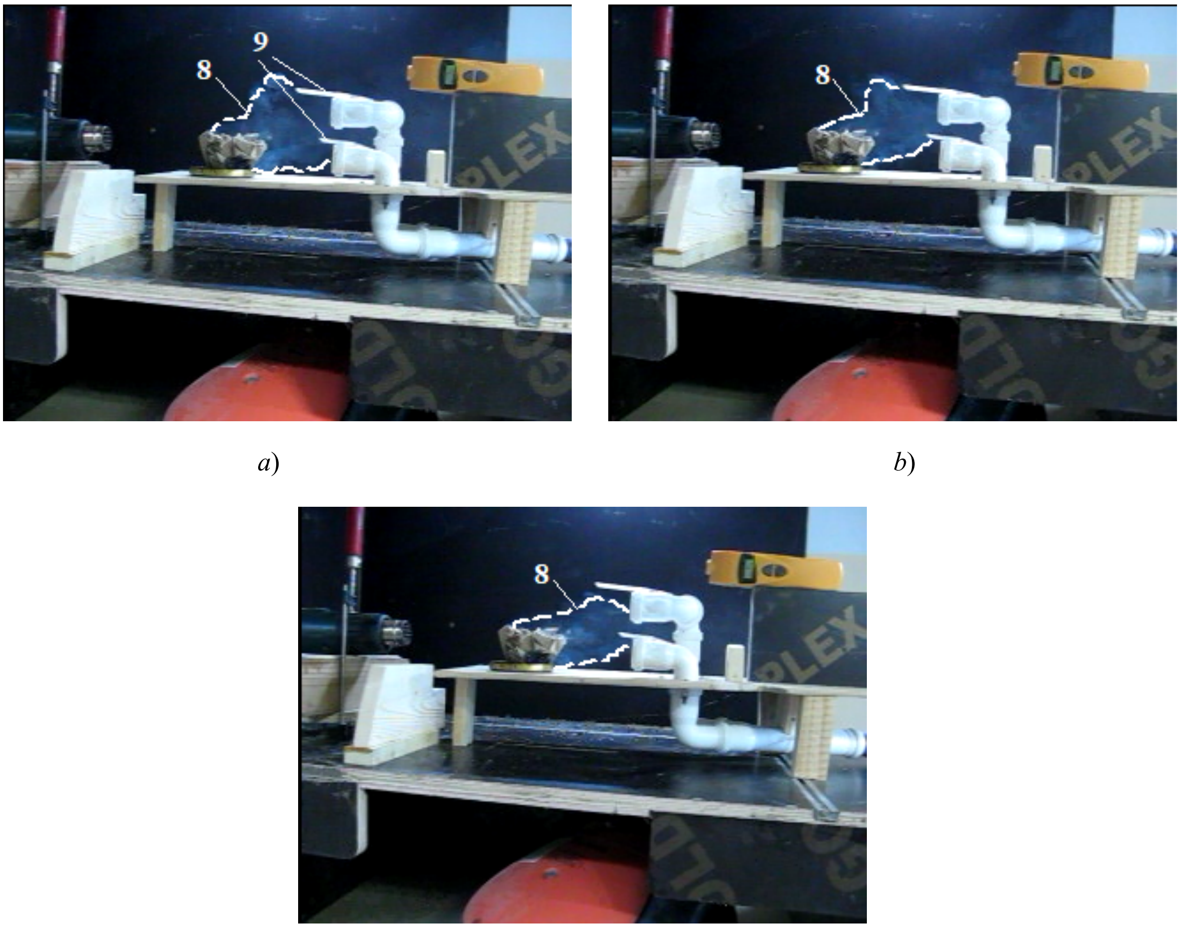
Analysis of the results of the laboratory experiment showed that the upper plate directs the gas flow to the area of the holes, and at the time t=8 s, the concentration was C=18 ppm (Fig. 3*b*), thereby connecting the upper hole of the exhaust system to a more active process of contamination selection in contrast to the situation where there were no plates and the upper hole was almost unable to take out contamination. During the time t=14 s, the pollution that was contained in the air above the second hole has already been sampled, but the lower and upper holes continue to simultaneously sample the pollution, the concentration decreases and becomes equal to C=8 ppm (Fig. 3*c*), in contrast to the case when the horizontal plates were of the same length, where C=14 ppm (Fig. 2*c*).

4. NUMERICAL MODELING

At the next stage of the study, a method was developed for the numerical calculation of the gas sampling process, which makes it possible to take into account the number of holes for the sampling of gases, their size, relative position, and the presence of guide plates of various lengths.

The local field of the air flow velocity, taking into account the operation of the exhaust gas intake pipes, is found from the solution of the Laplace equation for the gas flow velocity potential [23-24]:

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



a) *b*) *c*)

Fig. 3. Formation of a contaminated zone in the presence of guide plates of different lengths: *a* – at time t=4 s; *b* – at time t=8 s; *c* – at time t=14 s

The corresponding boundary and initial conditions are set (Fig. 4):

- at the boundary A the flow enters the computational domain, the Neumann boundary condition $\frac{\partial P}{\partial x} = V$ is set for the velocity potential, where V is the known value of the wind flow velocity $V = V_1 \cdot (y / y_1)^{n_1}$, where V_1 is the value of the wind speed at a certain fixed height y_1=10 m, $n_1 \approx 0{,}15 - 0{,}69$, as it depends on the roughness of the underlying surface and the class stability of the atmosphere, form was taken in the work $n_1 = 0{,}15$;
- at the boundary B, the flow leaves in the computational domain, the Dirichlet boundary condition $P = P_0 + const$ is set for the velocity potential, where P_0 is a certain numerical constant, taken 1000;

- at the boundary *C* the upper boundary, a solid impenetrable wall, the non-penetration condition $\frac{\partial P}{\partial y} = 0$ is set, as there cannot be an infinite boundary in numerical calculations, and then it is chosen at a sufficient distance, where the curvature of streamlines is insignificant;

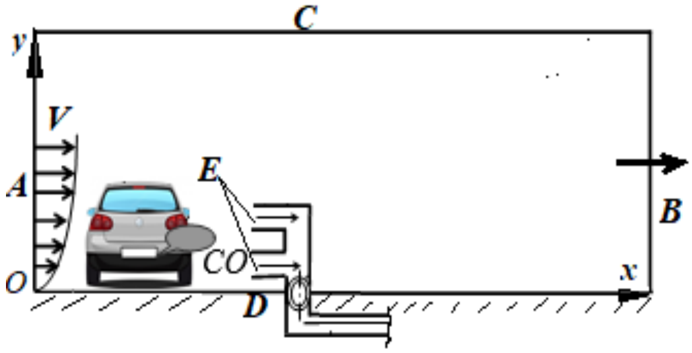


Fig. 4. Scheme of the computational domain for setting boundary conditions

- at the border *E*, the gas flow enters the exhaust gas extraction pipes, the $\frac{\partial P}{\partial x} = -V_0$ condition is set, where V_0 is the known value of the gas flow velocity, which is taken by the fan;
- at the boundary *D* the lower boundary, a solid impenetrable wall, the non-penetration condition $\frac{\partial P}{\partial y} = 0$ is set.

For the numerical integration of the Laplace equation (1), the Samarskii method [23] is used, the numerical implementation of which is described by dependencies (2)-(5).

First, the Laplace equation (1) is reduced to an evolutionary equation using the solution to be established in time:

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

where η is fictitious time, at $\eta \to \infty$; the solution of equation (2) tends to the solution of the Laplace equation. Namely, stationary equation (1) is the limiting case of non-stationary equation (2), i.e. when the solution to equation (2) stops changing in time and enters a stationary regime, then this is the solution to equation (1). This approach was introduced by A.A. Samarsky and G.I. Marchuk when creating splitting methods. To solve this equation, it is necessary to set the initial condition, the potential field at $\eta = 0$. For example, $P = 0$ can be taken in the entire computational domain at $\eta = 0$.

Difference equations in this case have the following form:

$$\frac{P_{i,j}^{n+1/2} - P_{i,j}^{n}}{0{,}5\Delta\eta} = \frac{P_{i+1,j}^{n} - P_{i,j}^{n}}{\Delta x^2} + \frac{-P_{i,j}^{n+1/2} + P_{i-1,j}^{n+1/2}}{\Delta x^2} + \\ + \frac{P_{i,j+1}^{n} - P_{i,j}^{n}}{\Delta y^2} + \frac{-P_{i,j}^{n+1/2} + P_{i,j-1}^{n+1/2}}{\Delta y^2}, \tag{3}$$

$$\frac{P_{i,j}^{n+1} - P_{i,j}^{n+1/2}}{0{,}5\Delta\eta} = \frac{P_{i+1,j}^{n+1} - P_{i,j}^{n+1}}{\Delta x^2} + \frac{-P_{i,j}^{n+1/2} + P_{i-1,j}^{n+1/2}}{\Delta x^2} +$$

$$+\frac{P_{i,j+1}^{n+1}-P_{i,j}^{n+1}}{\Delta y^2}+\frac{-P_{i,j}^{n+1/2}+P_{i,j-1}^{n+1/2}}{\Delta y^2}. \quad (4)$$

When using the Samarskii method, the numerical solution of the two-dimensional equation (2) to determine the velocity potential is carried out in two steps (3)-(4). The first one contains the "intermediate" value of the potential $P_{i,j}^{n+1/2}$ on the time layer «n+1/2», and the second – the "final" value of the potential $P_{i,j}^{n+1}$ on the time layer «n+1». The nonpenetration boundary condition is realized by using fictitious difference cells.

The found values of the velocity potential are used to calculate the components of the wind flow velocity vector on the faces of the difference cells at each time moment [23-24]:

$$u_{i,j}=\frac{P_{i,j}-P_{i-1,j}}{\Delta x},\ v_{i,j}=\frac{P_{i,j}-P_{i,j-1}}{\Delta y} \quad (5)$$

The spread of carbon monoxide in atmospheric air is modeled on the basis of the mass transfer equation [21-22, 24]:

$$\frac{\partial[CO]}{\partial t}+\frac{\partial u[CO]}{\partial x}+\frac{\partial v[CO]}{\partial y}=div(\mu grad[CO])+\sum_{i=1}^{N}Q_i(t)\delta(x-x_i)\delta(y-y_i), \quad (6)$$

where $[CO]$ is the concentration of carbon monoxide; u,v – components of the velocity vector; $\mu=(\mu_x,\mu_y)$ – coefficient of turbulent diffusion; Q_i – intensity of carbon monoxide emission; $\delta(x-x_i)\delta(y-y_i)$ – Dirac delta function; $(x_i,\ y_i)$ – coordinates of the location of the carbon monoxide emission source; and t – time.

To solve equation (6), the following boundary conditions are set:

- at the boundary *A,* the flow enters the computational domain, for carbon monoxide the boundary condition of the form $[CO]=[CO]|_0$ is fulfilled, the background concentration at time t = 0, and in the absence of data, the concentration value is taken to be zero;
- at the boundary *B,* the flow leaves the computational domain, and at the end of the computational domain in the numerical model, the boundary condition of the form $\frac{\partial[CO]}{\partial x}=0$ is fulfilled; from a physical point of view, this condition means that the diffusion process at the flow exit boundary is not taken into account; and
- at the boundaries *C*, *D,* and *E*, i.e. the non-penetration condition is realized on solid walls.

The numerical integration of equation (6) is performed on a difference grid using a five-step difference splitting scheme [21-22, 24].

The time derivative is approximated by the divided difference [23]:

$$\frac{\partial[CO]}{\partial t}\approx\frac{[CO]_{ij}^{n+1}-[CO]_{ij}^{n}}{\Delta t}. \quad (7)$$

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

$$\frac{\partial u[CO]}{\partial x}=\frac{\partial u^+[CO]}{\partial x}+\frac{\partial u^-[CO]}{\partial x};\qquad \frac{\partial v[CO]}{\partial y}=\frac{\partial v^+[CO]}{\partial y}+\frac{\partial v^-[CO]}{\partial y}. \quad (8)$$

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

$$\frac{\partial u^+[CO]}{\partial x}\approx\frac{u_{i+1,j}^{+}[CO]_{i,j}^{n+1}-u_{i,j}^{+}[CO]_{i-1,j}^{n+1}}{\Delta x}=L_x^+[CO]^{n+1},$$

$$\frac{\partial u^-[CO]}{\partial x}\approx\frac{u_{i+1,j}^{-}[CO]_{i+1,j}^{n+1}-u_{i,j}^{-}[CO]_{i,j}^{n+1}}{\Delta x}=L_x^-[CO]^{n+1}, \quad (9)$$

$$\frac{\partial v^{+}[CO]}{\partial y} \approx \frac{v^{+}_{i,j+1}[CO]^{n+1}_{i,j} - v^{+}_{i,l}[CO]^{n+1}_{i,j-1}}{\Delta y} = L^{+}_{y}[CO]^{n+1},$$

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

The velocity components *u* are determined on the vertical edges of the difference cells, and the velocity components *v* are determined on the horizontal edges. The indices of these edges correspond to the indices of the cells located to the right or above the corresponding border.

The second derivatives are approximated as follows:

$$\frac{\partial}{\partial x}(\mu_x \frac{\partial[CO]}{\partial x}) \approx \mu_x \frac{[CO]^{n+1}_{i+1,j} - [CO]^{n+1}_{i,j}}{\Delta x^2} - $$
$$-\mu_x \frac{[CO]^{n+1}_{i,j} - [CO]^{n+1}_{i-1,j}}{\Delta x^2} = M^{-}_{xx}[CO]^{n+1} + M^{+}_{xx}[CO]^{n+1}; \quad (10)$$

$$\frac{\partial}{\partial y}(\mu_y \frac{\partial[CO]}{\partial y}) \approx \mu_y \frac{[CO]^{n+1}_{i,j+1} - [CO]^{n+1}_{i,j}}{\Delta x^2} - $$
$$-\mu_y \frac{[CO]^{n+1}_{i,j} - [CO]^{n+1}_{i,j-1}}{\Delta x^2} = M^{-}_{yy}[CO]^{n+1} + M^{+}_{yy}[CO]^{n+1},$$

where $L^{+}_{x}, L^{-}_{x}, L^{+}_{y}, L^{-}_{y}, M^{+}_{xx}, M^{-}_{xx}, M^{+}_{yy}, M^{-}_{yy}$ are notations for difference operators. Taking into account the aforementioned notations, the difference analogue of the transport equation (6) is written as follows:

$$\frac{[CO]^{n+1}_{i,j} - [CO]^{n}_{i,j}}{\Delta t} + L^{+}_{x}[CO]^{n+1} + L^{-}_{x}[CO]^{n+1} + L^{+}_{y}[CO]^{n+1} +$$
$$+ L^{-}_{y}[CO]^{n+1} + \sigma[CO]^{n+1}_{ij} = (M^{+}_{xx}[CO]^{n+1} + L^{-}_{xx}[CO]^{n+1} + \quad (11)$$
$$L^{+}_{yy}[CO]^{n+1} + L^{-}_{yy}[CO]^{n+1}) + q_{ij}\delta_{ij}.$$

Designation δ_{ij} – number «1» or «0», depending on whether the source of pollution is in the difference cell «*ij*» or not. Values $q_{ij} = Q_i(t)/(\Delta x \Delta y)$, where $Q_i(t)$ is the intensity of the corresponding *i*-th source located in the difference cell «*ij*», and $\Delta x \Delta y$ is the area of this cell.

Difference equation (11) is split into five difference equations so that at each step only one direction of disturbance transport is taken into account, which is determined by the sign at the convective derivative. In this case, the difference equations take the following form:

– at the first step of splitting $k = 1/4$,

$$\frac{[CO]^{n+k}_{ij} - [CO]^{n}_{ij}}{\Delta t} + \frac{1}{2}(L^{+}_{x}[CO]^{k} + L^{+}_{y}[CO]^{k}) + \frac{\sigma}{4}[CO]^{k}_{ij} =$$
$$= \frac{1}{4}(M^{+}_{xx}[CO]^{k} + M^{-}_{xx}[CO]^{n} + M^{+}_{yy}[CO]^{k} + M^{-}_{yy}[CO]^{n}); \quad (12)$$

– at the second step of splitting $k = n + 1/2$, $c = n + 1/4$,

$$\frac{[CO]^{k}_{ij} - [CO]^{c}_{ij}}{\Delta t} + \frac{1}{2}(L^{-}_{x}[CO]^{k} + L^{-}_{y}[CO]^{k}) + \frac{\sigma}{4}[CO]^{k}_{ij} =$$
$$= \frac{1}{4}(M^{-}_{xx}[CO]^{k} + M^{+}_{xx}[CO]^{c} + M^{-}_{yy}[CO]^{k} + M^{+}_{yy}[CO]^{c}); \quad (13)$$

– at the third step of splitting $k = n + 3/4$, $c = n + 1/2$,

$$\frac{[CO]^{k}_{ij} - [CO]^{c}_{ij}}{\Delta t} + \frac{1}{2}(L^{+}_{x}[CO]^{k} + L^{-}_{y}[CO]^{k}) + \frac{\sigma}{4}[CO]^{k}_{ij} =$$

$$=\frac{1}{4}(M_{xx}^{-}[CO]^{c}+M_{xx}^{+}[CO]^{k}+M_{yy}^{-}[CO]^{k}+M_{yy}^{+}[CO]^{c});\qquad(14)$$

– at the fourth step of splitting $k=n+1$, $c=n+3/4$,

$$\frac{[CO]_{ij}^{k}-[CO]_{ij}^{c}}{\Delta t}+\frac{1}{2}(L_{x}^{-}[CO]^{k}+L_{y}^{+}[CO]^{k})+\frac{\sigma}{4}[CO]_{ij}^{k}=$$

$$=\frac{1}{4}(M_{xx}^{-}[CO]^{k}+M_{xx}^{+}[CO]^{c}+M_{yy}^{-}[CO]^{c}+M_{yy}^{+}[CO]^{k}).\qquad(15)$$

– at the fifth step of splitting, we take into account the source of pollution

$$\frac{[CO]_{ij}^{n+1}-[CO]_{ij}^{n}}{\Delta t}=\sum_{i=1}^{n}\frac{Q_i(t^{n+1/2})\delta(x-x_i)\delta(y-y_i)}{\Delta x\Delta y}.\qquad(16)$$

As a result, a forecasting method was developed, taking into account the presence of an exhaust system, which has a geometric shape. The air flow velocity field is calculated based on the numerical solution of the Laplace equation and the carbon monoxide concentration field when solving the mass transfer equation based on the finite-difference method. The computer program «Purifier» has been created, which allows carrying out a number of computational experiments to assess the effectiveness of two-level suction.

5. RESULTS OF COMPUTATIONAL EXPERIMENTS

The results of computational experiments are shown in Fig. 4. Geometrical dimensions of the exhaust system area are as follows: length – 7.5 m; height – 3.5 m; turbulent diffusion coefficient – $\mu_x=\mu_y=2{,}01$ m^2/s; the intensity of carbon monoxide intake from vehicles – 0.02 g/s; diameters of holes – 0.3 m, distance between nozzles – 0.3 m; length of plates 0.3-0.6 m; the rate of selection of carbon monoxide by the lower hole is 20 m/s and the upper hole is 15 m/s; and O*y* axis – directed vertically upward. The coordinates of the source of *CO* emissions are location of the vehicle exhaust outlet. In the model, it is assumed that this is a point source of emission; therefore, in the mathematical model, it is specified by the Dirac delta function δ_{ij}, and in the numerical model, by the position of the difference cell in which the emission source is located, namely, $Q=Q_{\text{source}}(t)/(\Delta x\Delta y)$, where $Q_{\text{source}}(t)/(\Delta x\Delta y)$ is the real *CO* emission from the car [r/s] and $(\Delta x\Delta y)$ is the area of the difference cell. The model does not take into account the exhaust speed, as the road is modeled as a set of point sources. As a two-dimensional model is used, the wind direction is chosen across the highway (along the O*x* axis).

As the outlet of the suction pipe is round, the distribution of the suction speed over the cross section is uneven, namely, it is more on the axis, and less closer to the walls, which is caused by the deceleration of the flow. For this accounting, it is necessary to use a difference grid, which leads to a significant increase in the computation time. As "express" models are considered, then in these studies it is assumed that the suction rate is the same over the entire cross section of the exhaust outlet.

The results of chemical pollution for the first scenario, when the polluted air was sampled through two holes without guide plates, are shown in Fig. 4*a* [21]. For the second scenario, when guide plates of the same length were installed on the upper part of the nozzles, the dimensions of which were commensurate with the diameters of the holes, the results of the computational experiment are shown in Fig. 4*b* [22]. The presence of the guide plates reduces the velocity at the level of the holes according to the laws of hydrodynamics; moreover, the plates help direct the flow toward the holes, which was qualitatively proved by a physical experiment (Fig. 2*c*). For the third scenario, the use of such plates, when the length of the upper plate is twice the length of the lower one (Fig. 4*c*), makes it possible to more effectively reduce the level of *CO* concentration.

The results of experimental measurements and calculated data obtained using the developed method and software package are shown in Table 1. The discrepancy between the numerical and experimental data is about 15-20%. Thus, the use of two-level exhaust systems can reduce the concentration of pollutants by 46-68% in comparison with its absence.

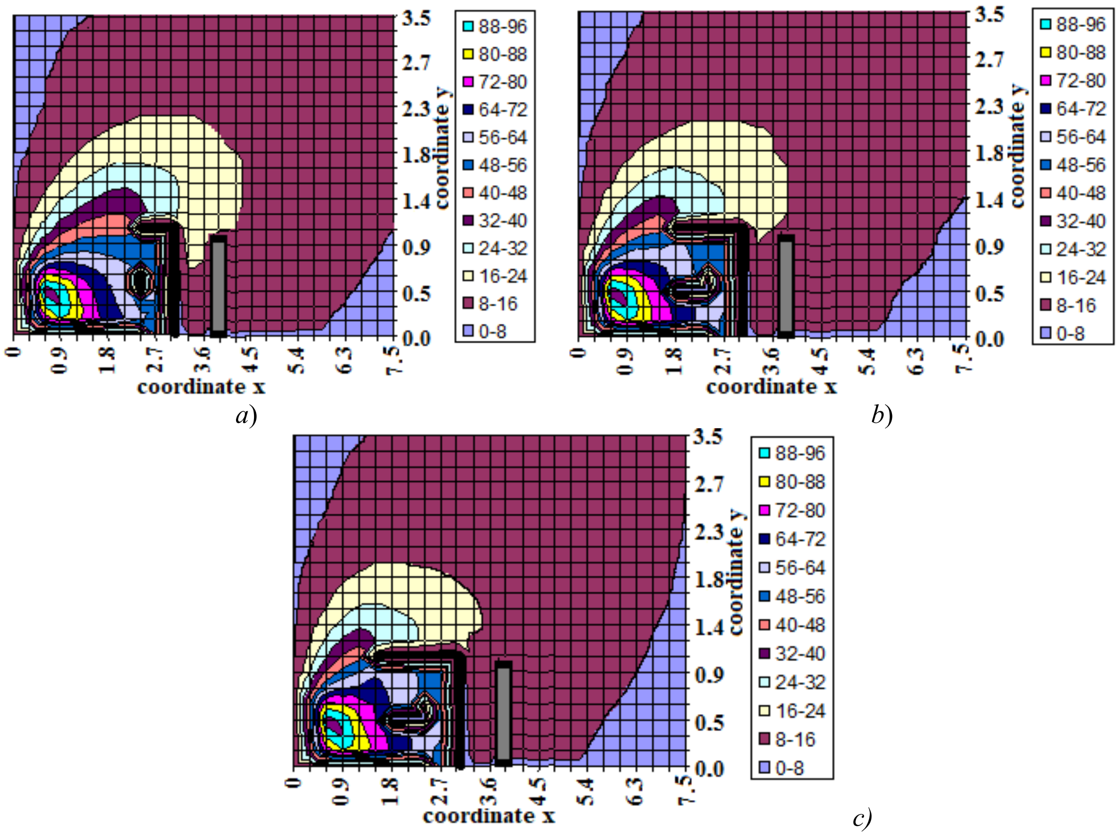


Fig. 5. Formation of the contamination zone t=14 s: *a* – absence of guide plates; *b* – presence of guide plates of the same length; and *c* – presence of guide plates of different lengths, the upper one of which is longer

Table 1

Results of experimental measurements and calculated data of *CO* concentration

Time, s	*CO* concentration, ppm (experiment / numerical) without guide plates	*CO* concentration, ppm (experiment / numerical) with guide plates of the same length	*CO* concentration, ppm (experiment / numerical) with guide plates, the upper one is longer
4	(42-44) / 39	(35-38) / 31	(28-30) / 23
8	(33-36) / 29	(26-30) / 21	(18-–26) / 16
10	(29-32) / 25	(18-24) / 16	(12-16) / 10
14	(21-23) / 18	(14-16) / 12	(8-10) / 7

6. CONCLUSIONS

On the basis of the conducted experimental studies, the main regularities of the air flow were revealed depending on the geometry of the exhaust system, namely, through the use of not one but two gas sampling holes.

It was found that in the presence of horizontal plates on the holes of the suction nozzles, the concentration of carbon monoxide significantly decreases. Equal-length guide plates reduce the concentration level by 44 %, whereas different guide plate lengths by 62% compared with none.

A method of numerical calculation for the gas sampling process has been developed, taking into account the number of sampling holes, their sizes, and mutual arrangement. A software package has been developed that makes it possible to carry out the required number of computational experiments, as carrying out field experiments takes a long time and is costly.

The studies made it possible to calculate and analyze the field of carbon monoxide concentration. It was found that the usage of two-level exhaust systems with guide plates at the gas flow sampling holes can significantly reduce the concentration of pollutants.

The further direction of these studies is supposed to be carried out in the direction of studying the effect of a vertical screen on the upper nozzle of the exhaust system on the localization of pollution zones near motorways.

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