Protection of residential buildings from vehicle emissions using landscaping areas of various design

V V Balakin
Institute of Architecture and Civil Engineering of Volgograd State Technical University, 1, Akademicheskaya Street, Volgograd 400074, Russia
E-mail: balakin-its@yandex.ru

Abstract. The gas protection efficiency of green spaces on highways and transport infrastructure objects in residential areas and historical centers of cities has been studied in this article. The most effective protection of roadside areas from gas contamination is provided by dense landscaping strips. The rows of plants closest to the edge of the roadway should be represented by shrubs that form two-tiered hedges, and trees with a low crown. In such rows, the height of woody plants should be gradually increased to form a step-shaped strip per cross section. In order to expand the zone of gas-protective influence of landscaping strips, it is necessary to provide for ordinary planting of high-growing trees in their composition. If the street width is not sufficient to accommodate linear-lane structures of green spaces with the maximum density with a value of the openness coefficient $K$, close to 1, it is necessary to form landscaping strips of optimal density with a value $K=0.5...0.6$. On streets with multi-section front buildings in green belts, the most preferable is the height of trees at the level of the middle floors, which provides lower concentrations in front of the strip and uniform dispersion of ingredients at the walls of buildings, as well as intensive air exchange in the pedestrian traffic zone.

1. Introduction
When greening transport infrastructure in cities where car flows form systems of linear sources of noise and gas pollution of the residential environment, it is necessary to use the most effective architectural and landscape compositions and structures of green spaces, taking into account their environmental properties. However, in the conditions of increasing density of transport communications within the borders of urbanized territories, vegetation is displaced and a special type of natural and anthropogenic landscape is formed, characterized by a violation of the unified structure and an increase in rigidity due to the monotonous repetition of building surfaces, street coverings and their color. As a result of intensive use of urban space with a high degree of landscape fragmentation, urban ecosystems do not meet the requirements of architectural and landscape organization of the territory and do not ensure the performance of their environmental and aesthetic functions [1-8].

Methods of greening transport infrastructure facilities should focus green spaces on the maximum implementation of their environmental protection potential. To this end, it is necessary to choose their optimal location in relation to sources of negative impact on the residential environment, as well as objects of protection within residential zones, to determine the rock composition, density and geometric characteristics of the structures being formed.
In the conditions of overbuilt insufficiently ventilated urban streets and adjacent territories, the dominant environmental factor that reflects the level of negative impact of transport on urban environmental systems is the gas content in the atmospheric air in combination with aeration regime. Concentrations of the leading components of car exhaust gases in the air of main roads and streets are associated with an inverse functional relationship with wind speed. The wind conditions of streets and intra-block territories are actively affected by buildings, irregularities of the underlying surface, elements of landscaping and tree and shrub plantations.

In contrast to buildings and impenetrable elements of landscaping, which can cause only the circulation movement of a turbulent jet in the process of their air flow, trees and shrubs are partially permeable obstacles, behind which there is a mixture of two turbulent jets – passing through the barrier and circling it from above [9]. Due to this aerodynamic property, the level of air pollution by the roadside strip of green spaces is reduced by partial absorption of car emissions by woody and shrubby vegetation [10], as well as, and mainly, by dispersion into the upper atmosphere due to the aerodynamic properties of the tree belts [11, 12]. Therefore, the number of rows of trees and shrubs, the shape and density of their crowns should be established, first of all, in terms of their dispersing ability, when forming garden protection strips.

The leading role in the transformation of air flows and dispersion of atmospheric pollutants is played by the height of landscaping strips, the width, shape and density of their crowns, the nature of the stem, the spacing of tree planting in a row, the size of row spacing and the dendrological composition of plantings [9, 11]. These characteristics determine the closeness of woody plants in rows, the density of their phytomass and the frontal structure of landscaping strips in general [13], as well as the surface area of deposition and absorption of ingredients [12].

On main roads and streets, the choice of the structure, location and range of green spaces is determined by transport, planning and micro-climatic factors, which ensure the protection of pedestrian zones and residential areas from the negative impact of transport, a decrease in air temperature in the summer, and in some cases, local wind protection.

According to the observations of A.V. Gorodkov, the environmental effectiveness of the landscaping strip depends not on its width, but on the density of trees and shrubs. The highest density of branching and leafing is characteristic of the most illuminated fringe rows of tree and shrub plantations consisting of principal species and forming a "stepped" cross-section of the environment-protective belts [13].

The expansion of such shelter belts is possible only by increasing the number of internal rows of trees. However, the degree of phytomass density of these series is insignificant. It follows that the density and volume of phytomass of the expandable strip do not increase in direct proportion to the increase in the number of rows and its total width, but to a much lesser extent. In shelter-belt establishment, this feature of forest strips makes it possible to reduce their width and area on the slopes to a certain minimum without noticeably weakening the wind protection efficiency [14].

Hence, it is necessary to determine the optimal width and density of landscaping strips taking into account their environmental properties on urban roads and streets. Their width along the lines of development is regulated by building regulations and enables to place landscaping strips with a limited number of rows of trees and shrubs.

2. Methods used in the experiment

The study of the gas-protective role of green space strips was performed on the main streets of Volgograd and by modeling on an open flat area of 100 × 150 m covered with asphalt concrete. The model of the green space strip was a 1: 20 scale screen made of metal mesh and synthetic fiber of a certain density.

The coefficients $K$ characterizing the belt density as a quotient of dividing the area of the belt without gaps by the total area of the frontal projection of the tested model were determined beforehand. To this end, the models were photographed from the same distance on a light background. Then the resulting negatives were placed into the camera of the photoelectrocolorimeter FEC–56 and
their optical density was determined. The coefficients of openness for the belts were obtained by dividing the optical densities of model negatives by the optical density of the illuminated photographic film – the "impenetrable screen".

The experiment also used models of buildings made of thin wood slabs. Sections of street models with a length of 300 meters were oriented with a longitudinal axis perpendicular to the direction of the wind prevailing at the test site.

The line pollution source was a pipeline with small diameter pipes evenly distributed along its length connected to the exhaust system of an automobile engine.

Air samples were taken by drawing it through absorption vessels using sampling tubes and air aspirators in the nodes of a grid of points evenly distributed along the vertical cross-section of the street.

Based on the results of the analysis of air samples, the concentration fields of total nitrogen oxides ($NO + NO_2$) in the air were obtained according to the schemes "line source – green strip" and "line source – green strip – building", as well as in open space.

3. Results and discussion

The results of field observations showed that in an open area in the direction perpendicular to the road, the decrease in the concentration of exhaust gases dropsexponentially at a distance of up to 30 m. Then the scattering of gases is proportional to the distance from the source.

There is minimal gas contamination behind the green belts at a distance of up to one height of the strip. The maximum concentrations of ingredients in the air are observed at a distance of 1.5 to 3 heights in the zone of contact with the part of the gas-air flow that goes around the strip from above. This confirms the above statement that the green strips are semi-permeable screens that can deflect and disperse some of the exhaust gases in the upper atmosphere. The other part of them infiltrates through the branches and leaves.

When the density of landscaping strips increases to values $K=0.5...0.6$, the most intense dispersion of car emissions is observed. Then the increase in the gas protection efficiency of green belts occurs more smoothly.

With the formation of the city environmental system "roadway-green lane-building", the aeration regime and changes in exhaust gas concentrations within the sidewalk part of the street become more complex. Figure 1 shows the $NO + NO_2$ concentration fields on the cross-section of the street that are formed when plantation strips interact with the front building. In this case, due to the convective counter flow on the windward side of buildings, the speed of descending turbulent jets due to the general circulation of the air flow decreases. At the same time, semi-permeable obstacles in the form of rows of trees and shrubs can have a noticeable inhibitory effect on the speed of the circulation flow and the formation of exhaust gas concentrations in the street space [15].

The results of experiments show that the nature of the impact of green space strips on the formation of concentrations of pollutants in buildings and on pedestrian sidewalks, as well as in the inner space, significantly depends upon their relative height. If the height of the strip ($h$) and the building ($H$) are equal, there is an increased level of gas contamination of the air near the building line (Figure 1a, 1c). And at $h = 0.5H$, there is a significant dilution of impurities on the facades of buildings and in the pedestrian traffic zone where an intensive turbulent exchange is stimulated. (Figure 1b, 1d). Obviously, the height of trees should be limited at the level of the average floors of buildings by carrying out structural felling, felling care, tree surgery and clippings.

When the heights of trees and buildings are equal, there is a decrease in air pollution along the courtyard facades and in the interior space due to an increase in the trajectory and dispersion of exhaust gas components in the upper atmosphere (Figure 1a, 1c). However, landscaping strips consisting of trees with dense crowns are secondary sources of air pollution with impurities on the street itself.
Green belts also significantly change the distribution of car emissions on streets with dense two-side development with canyon configuration associated with major environmental problems, in terms of their aeration and gas pollution [16–17]. When the wind direction is from left to right, a recirculating vortex flow is formed on streets with a width of $B<3H$ (here $H$ is the height of buildings), rotating clockwise. In addition, at the lower floors of the first building, in the corner formed by its leeward wall and the surface of the street, a closed vortex of a small size occurs inside which impurities coming from the roadway with the main vortex flow are retained and circulate at a low speed [18].

In order to avoid the stagnation of pollutants on densely built-up, insufficiently ventilated sections of main streets where harmful ingredients drift at a low speed near the apartments of the lower floors, linear-belt structures of green spaces must be formed by permeable shelter belts using high-stamp trees as the main species. The best conditions for the movement of air masses through areas of plantings can also be provided by increasing the spacing between rows of woody plants.

4. Summary and conclusions
The operation of transport infrastructure facilities is accompanied by a negative impact of transport on the main environmental systems – the atmosphere, reservoirs, soil, biota and living conditions of the population in cities. Green spaces can withstand the negative impact of transport on residential areas adjacent to transport infrastructure. On main roads and streets, landscaping means achieve the harmonization of hard landscapes with the restoration of their softness and aesthetic appeal to urban residents.

However, in the planning zones and historical centers of large cities, in the conditions of space scarcity resulting from the saturation of engineering communications, the need to pass high-intensity traffic flows, storage of cars and ensuring the interaction of ground and high-speed off-road transport, there is an acute problem of preserving and increasing the share of natural and green areas.
Within urbanized territories, the environmental protection potential of tree and shrub plantations will be fully manifested if their structure and species composition are chosen correctly. Reducing the level of air pollution by roadside green spaces occurs through partial absorption of car emissions by woody and shrubby vegetation, as well as, and mainly – due to precipitation and dispersion into the upper atmosphere due to the aerodynamic properties of landings. The permeable strips differ in insignificant gas protection efficiency due to the fact that most of the gas-air mixture freely passes through the corridors formed under the crowns of roadside planting.

The most intensive increase in the gas protection efficiency of landscaping strips is observed when the openwork coefficient $K$, which characterizes their density, increases to average values, and then their gas protection efficiency increases more smoothly. This should be taken into account if there are technical dividing lines for engineering communications, where the conditions of their operation do not allow the planting of trees. In these conditions, the width of streets along the lines of development prevents creating strips of tree and shrub plantations with a $K$ value close to 1. In this case, it is necessary to form landscaping strips with $K=0.5...0.6$. this density can have two-four-row tree planting with two rows of shrubs with a total width of 8...15 m.

On streets with multi-section front buildings, the most effective in relation to the exterior facades of buildings and pedestrian traffic zones are strips of even open and permeable design at the height of trees at the level of average floors. In this case, lower concentrations of ingredients are observed in front of the strip and their uniform dispersion near the walls of buildings facing the source. To eliminate the focal nature of the distribution of exhaust gases in the street space, it is necessary to limit the height of green spaces to half the height of buildings by structural logging.

As the height of the green space strip approaches the height of buildings, the concentration of exhaust gas components in the air in the courtyard space decreases due to an increase in the length of the path of movement of the gas-air mixture in the upper layer of the atmosphere. However, when trees are planted thickly, impurities accumulate in the street space in high concentrations. Therefore, dense planting of high-grown trees should be used in combination with low-rise non-residential buildings to provide protection from the negative impact of transport in more remote residential areas built up with high-rise buildings.

Along with the correct planning solution of landscaping objects, architectural and aesthetic qualities and the necessary attractiveness of the formed landscape for urban residents must be provided. Ordinary plantings and groups of trees and shrubs, hedges should fit into the spatial composition of transport structures, do not interfere with their functions and perform their task of creating a comfortable urban environment in residential areas.

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