Protection of pedestrian zones and residential areas from vehicle emissions by trees and shrubbery planting technique

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Abstract. The article describes the results of in-situ observations and physical model experiments for dispersion of automobile exhaust pollutants by planted areas in urban streets and roads. Structure and composition of protective planting is defined for better dispersion of car emissions. In the “road-shelterbelt-building” system, if the belt height is about half the height of the building, the most effective dilution of pollutants along the building façades and at the pedestrian ways is observed. As the belt height approaches the height of the buildings, the air in yards of the buildings is still cleaner because of the longer way the pollutants have to travel, but then they accumulate within the street space. The shelterbelts for the densely built-up stretches of heavy-traffic streets should be of permeable structure to prevent pockets of stationary air; this ensures the necessary air interchange at the pedestrian ways and also more even pollutant dispersion at the building façades. Guidelines are provided for linear and strip protective/decorative plantation structuring for bringing the environmental discomfort factors in residential areas down to the environmental standards.

1. Introduction
Pedestrian movement on urban streets closely connected with residential construction, objects of cultural and social services and trade becomes more and more wide scale in big, large and largest cities and requires “provision with comfort and safety for pedestrians, reducing noise level and air pollution with waste gases” [1], as well as forming a favorable microclimate.

In this regard, when redeveloping elements of street network within the urban residential area including pedestrian and transportation streets assigned in a separate category [2], there appears a need to form special shelter-belts with a complex environment protective purpose.

Forming objects of green plantation in the transportation zones exposed to man-made impact is naturally connected with solution of the most common task of “reconstruction, designing, and restoration of urban landscapes (cityscapes)” [3]. Urban areas occupied by the transportation infrastructure objects differ by a transformed “special type” of natural and anthropogenic landscapes to a high degree. Its typical features are reduction of the “softness” and increase of the “severity” due to the reduction of green cover area, growth of built-up density, etc. As a result of intense use of urban space here, “plant complexes (geobiocoenosis) have disappeared which should carry out environment forming, nature-protective, and aesthetic functions” [4,5].

In terms of the ecology, the position and behavior of humans in such a space are deteriorating. City gardens are used as major means of forming the “space and spatial composition and the area structure”, reducing the “tensions and proneness to conflicts” [4] in the urbanized environment.
Herewith, harmonization is reached between “harsh landscapes” with the “continuous and faceless
development” and the limited green cover by way of “erasing boundaries between architecture and
nature” [3] recovering their “softness”, improving the aesthetics, and enhancing the attraction.

Along with this, the green plantations are a major component of any cityscape taking part in the
processes of accumulation, transformation, and removal of air pollution out of urban environment in
combination with grass cover and soil. Gases are not only accumulating in the plant leaves and needles
but also are translocated along the organs and removed into the roots and soil. Tree and shrubbery
plantings (shelterbelts) can absorb and involve into the metabolism sulphur dioxide, nitrogen oxides,
ammonium, and other ingredients assimilating them with the leaves [6,7]. The green plantations play
an especially great protective role on the objects of transportation infrastructure where there is a mass
emission of harmful exhausts from vehicles at a low height directly into the human breathing zone and
into the residential development.

The landscape-environment protective compositions and linear-band structures of green plantings
are widely used on the major highways and streets where “the linear forms of pollution are observed”
[3], to a high degree, in the shape of alternate continuous planes represented by straight-lined,
curvilinear and also positioned along the zigzag “walls” separating the residential area from the
carrigeway. However, “techniques and traditions in urban plantings as well as the landscape-aesthetic
principles of their design” [8] existing at the modern time do not provide environmental well-being
and comfort on the arterial areas to the fullest extent yet.

The greenery planting techniques employed within the urbanized territories should orient both the
reconstructed existing and the newly designed plantings to the maximum use of their environment
protective potential. In the transportation areas, it will reveal itself in their optimum planning position
both in respect to the discomfort sources – transportation flows and parking lots, and to the objects of
protection – residential and public buildings, children’s preschool institutions, schools, the correct
choice of structure and the species composition.

Trees and shrubbery are partially penetrable obstacles behind which mixing of two turbulent
streams occur - one going though the obstacle and an enveloping one [9]. Due to this aerodynamic
property, the reduction of the air pollution level by the roadside shelterbelt is carried out partially by
absorption of certain components of vehicles’ waste gases (WG) with the leaves [10], as well as – and
mostly – due to their dissipation in the environment enveloping it with the air flow from above [11]. In
this connection, the objective of the research was studying the laws of the WG dissipation by the
shelterbelts of various designs on the major streets revealing the effects of gas reduction in pedestrian
zones and in residential areas.

2. Methods used in the experiment
The studies of gas-proof functions of green plantings have been carried out in natural conditions on the
streets of large cities and on the testing ground for large-scale modeling [12-14] using models of belts
of trees and shrubbery plantings with dense, open-planted and blow-through constructions
characterization of which is given in works by Ya.A.Smalko [11] and F.L.Serebrovsky [9]. The
models had the form of metal wire frames in the scale of 1:20 and filled with synthetic fiber to the
preset density.

Preliminarily, a coefficient of openness for each shelterbelt has been fixed as the relation of the
obstacle area on the way of WG expansion – the frame elements and the synthetic material – to the
general area of its frontal projection [15]. For this purpose, the models were photographed on the
bright background, and then the obtained negatives were placed into a camera of the photoelectric
colorimeter FEK-56. Coefficients of greenbelt openness were determined by comparison of optical
densities of model negatives and the beta screen. Coefficients of openness for shelterbelts in the
natural conditions were determined by the same method.

As a source of the WG, a special pipeline was used imitating the linear source – traffic flow which
had been connected to a vehicle exhaust pipe. A mix of gases was coming out of tube openings evenly
and strictly horizontally on either side of the main pipe which excluded the impact of the initial speed
and the direction of their exhaust on the vector of the air flow speed at the point of determination of the initial concentration of the components under study. As follows from the analysis of air samples selected at the network nodes spaced at height-wise intervals of 1.5 m at the distances multiple of the plants’ height, concentration fields for the carbon oxide (CO) and nitrogen oxides (NO+NO₂) were obtained in the vertical plane within urban ecosystems “carriageway-shelterbelt” and “carriageway-shelterbelt-building”. The gas protective efficiency of the shelterbelts was determined by the formula:

\[
\omega = (1 - q_e / q_0) \times 100,
\]

where \( q_0 \) and \( q_e \) – concentrations of the WG components in front of the screen and behind it, mg/m³.

### 3. Results and discussion

The studies showed that the reduction of the WG concentration by the green plantings’ belts on the road largely depends upon 2 indices: density and height. Table 1 shows the gas protective performance factors for green planting techniques most often occurring on the traffic infrastructure objects.

**Table 1. Reduction of CO concentration by green shelterbelts (in %).**

| Shelterbelt structure | Height, m | Width, m | Density, rate | Protective efficiency, % |
|-----------------------|-----------|----------|---------------|--------------------------|
| One row of trees, one row of shrubbery | 5...8 | | 0,2...0,4 | 17...28 |
| | 8...10 | 4...6 | 20...32 |
| | 10...15 | | 18...29 |
| Two rows of trees, two rows of shrubbery | 5...8 | | 28...41 |
| | 8...10 | 8...10 | 29...43 |
| | 10...15 | | 32...47 |
| Three to four rows of trees, two rows of shrubbery | 5...8 | | 33...45 |
| | 8...10 | 10...15 | 34...47 |
| | 10...15 | | 37...51 |
| Five to six rows of trees, two rows of shrubbery | 5...8 | | 37...48 |
| | 8...10 | 20...30 | 38...50 |
| | 10...15 | | 42...55 |

These data indicate that the most efficient protection of pavements and the adjacent territory from the WG penetration out of the carriageways is provided by dense tree and shrubbery plantings with the width of 15...30 m. However, the WG concentrations within the thick plantings of trees and shrubbery turn out to be higher compared to the open area. In this case, the belt of thick impermeable construction like a forest area “start playing a role of pollutant accumulator” [16] due to the sharp decrease of the wind speed (Figure 1).

By the position of the curves in Figure 1 and Figure 2, it is seen that the environment protective plantings in combination with the buildings are especially sensitive to the change of their relative height. If, with the equal height of the belt (\( h \)) and the building (\( H \)), there are enhanced concentration of the WG components in the walkway part (Figure 1, curve 4), then at \( h = 0.5H \), there is a considerable dilution of pollutants directly behind the shelterbelt – in the pedestrian zone and in front of the buildings where an intensive turbulent interaction is stimulated (Figure 1, curve 2).
Figure 1. Change in the concentration of NO+NO\textsubscript{2} in the air at the level of 1.5 m at the street cross-section with the 9-story frontal development under the impact of 4-row trees and 2 row shrubbery: 1 – at $h = 0.3\ H$; 2 – $h = 0.5\ H$; 3 – $h = 0.7\ H$; 4 – $h = H$; 5 – without greenery. $h$ – height of green belt, m; $H$ – height of a building, m. 100% – content of NO+NO\textsubscript{2} in the air at the level of 1.5 m above the kerb.

Figure 2. Vertical profiles of CO concentration at the residential multi-section buildings faces under the interaction with the green belt in a blow-through structure: a – at $h = H$; b – at $h = 0.5\ H$ Dotted line – CO concentration profiles in front of buildings without landscaping. 100% – content of CO in the air at the level of 1.5 m above the kerb.

In the course of the experiment, it was stated that the character of vehicles’ exhausts dispersal in the system “carriageway- shelterbelt-building” largely depends both upon the construction, the height of the shelterbelt, and the number of stories in a building, and upon the distance between them, that is the width of the walkway. In combination with the building system, the belts of permeable and equally open constructions with the planting height equaling half of the buildings’ height are more efficient relative to pedestrian zones and the lower building stories (Figure 2, b). In this case, an intensive turbulent interaction in the walkway part is stimulated and an even distribution of the WG components along the buildings’ facades is provided. The reduction of CO and NO+NO\textsubscript{2} concentrations by the 4-row tree belt with the two row shrubbery at the 5-story building system reaches 85%.

On approaching of tree height to the buildings’ height in the shelterbelts of evenly-open (Figure 2, a) and dense (thick) (Figure 3, a) construction, an extra decrease of air pollution at their courtyard facades and in the inner block area due to the expansion of the transfer and dispersion of pollutants way in the upper layer of the atmosphere. However, in this case, thick plantings in combination with the buildings revealing better indices of gas protective efficiency relative to the courtyard space with the height increase, serve as the secondary source of air pollution in the street with the accumulated pollutants held within the shelterbelt (Figure 1).
Figure 3. Vertical profiles of CO concentration at the residential multi-section buildings faces under the interaction with the green belt of dense structure: a – at \( h = H \); b – at \( h = 0.5H \). Dotted line – CO concentration profiles in front of buildings without landscaping 100% – content of CO in the air at the level of 1,5 m above the kerb.

4. Summary and conclusions

On the sections of highways and other objects of transportation infrastructure, a special type of natural and anthropogenic landscape is formed characterized by disjointedness, lack of unity in the structure, and increase of “hardness” due to the removal of green cover.

Green shelterbelts are major components in the ecosystem able to withstand the negative impact of traffic upon the living environment in the especially vulnerable in terms of ecology territories close to highways. Upon the highways and streets, a harmonization of “hard landscapes” is achieved by the green plantings restoring their “softness” and aesthetic attraction.

The techniques of transportation infrastructure planting should orient the plantation to maximum realization of their environment protective potential. To achieve this goal, it is necessary to determine their optimum position in respect to the traffic flows, parking lots, and hazardous locations within residential areas, as well as the species composition, density, and geometrical characteristics of the formed structures.

Trees and shrubbery present partially permeable obstacles which divert some traffic emissions into the upper layer of the atmosphere and scatter them. Herewith, the other part of the emissions can be absorbed by the shelterbelt when passing through branches and leaves. The leading role in the transformation of the air flows through the shelterbelts and scattering of vehicles’ emissions is played by their height, crown shape and density, the character of tree trunk, in-the-row spacing, size of row spacing, and the dendrological composition of plants.

The most favorable in the system “carriageway - shelterbelt” are linear-striped structures of green plantings of the thick impermeable construction with the width of 15...30 m. Their gas protective efficiency is by 30 % higher than with permeable (open) ones due to the more pronounced insulating power. To broaden the zone of the gas protective activity, it is needed to incorporate multi-row plantings of highly growing trees (poplar trees – white, black, “Canadian” ones, maple trees, et al.) and shrubbery.

In combination with the buildings in the shelterbelt, the most favorable height of trees is that equaling half of the building height providing their maximum gas protective efficiency. When reaching the trees’ height half of the buildings’ one, it is necessary to limit their growth and to prevent the crown development toward the carriageway in the shelterbelts by constructional cuttings, cleaning cuttings, tree surgery, and topiary works. For these purposes, when planting shelterbelts on the highway sections with continuous frontal development, it is necessary to select trees of such species that can easily endure the trunk cutting and give many shoots on the tree trunks.
Green planting zones out of large-sized trees with thick crown should be used both in the isolated version and in combination with the non-domestic buildings to protect the residential areas considerably detached from carriageways from the negative impact of transportation.

The shelterbelts should be gas-resistant enough and capable of absorbing harmful substances. For these purposes, it is recommended to plant the field maple, white and black poplars, horse chestnut, cotoneaster, hawthorns, spindle tree, ninebark, snow-berry [17]. When selecting the list of plants in the environment protection belts, it should be remembered that their gas proof efficiency largely depends upon the structural features of tree crowns and shrubbery of various species, as well as upon their age and seasonal variability.

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