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INFLUENCE OF A CERTAIN TYPE OF ROADSIDE BUILDINGS ON THE DISPERSION OF AUTOMOTIVE POLLUTANTS

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ABSTRACT

The paper presents an experimental and computational study of air pollution in megacities of Kazakhstan: Almaty, Astana, Shymkent, namely on the streets with the most intense vehicular traffic. Objective of the study is to study a consistent pattern of air pollution by road traffics given different types of urban buildings. We have instrumentally measured the concentration of carbon oxide and nitrogen dioxide pollutants at different distances on both sides of a highway to determine a dispersive property of the corresponding buildings. In order to study the air change conditions, we used a characteristic of the structure front line along the highway. A structure openness factor A_{op} was applied as the characteristic.

The study, which is aimed to determine the influence of roadside buildings on the CO and NO_2 pollutants dispersion, has found that the highest concentration is observed in the most built-up areas; rates of decline in the concentration of nitrogen dioxide are higher than rates of decline in carbon oxide. Given this, we can assume an unfavorable accumulation of carbon oxide in the surface atmospheric layer in roadside areas. In order to protect the atmospheric air from automotive pollution, it is necessary to take the city-planning measures to reduce the concentration of exhaust gases in the human habitation area.

Key words: Atmospheric air, Vehicles, Exhaust gases, Pollutants, Roadside buildings, Openness factor.

INTRODUCTION

Air pollution is one of the main reasons for the negative impact on the environment and human health. Vehicles are the main source of air pollution in most cities. Total contribution of vehicles in urban atmospheric pollution is estimated in the range of (40-60) % and in case of adverse weather conditions - up to 100%[2-3]. Development of urban

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transport results in the growth of cities, boosts the transportation mobility of the population and leads to a large amount of exhaust gases, which are constantly accumulated in the environment. At the same time, the pace of development of the road and street network is behind the growth of the vehicle fleet. Most city streets, especially streets in the downtown, do not comply with technical standards as they were designed without taking into account the high density of the road traffic. This fact is a prerequisite for a problematic traffic, the so-called 'traffic jams' and air pollution by toxic exhaust gases. The current unfavorable situation is dramatized by the fact that urban population is also subject to the impact of automotive pollution. The extent of the automotive pollution impact on the environment is determined by the ground-level concentration of pollutants in the atmospheric air, while the extent of gas contamination in highway and roadside areas depends on the traffic intensity, street width and relief, wind speed, share of trucks and buses in total traffic, and other factors[3,4].

People have started to study the dispersion of pollutants from transport sources relatively recently. Probably for this reason the existing methods of forecasting and modeling the air pollution in cities are far behind the existing computational methods aimed to determine the concentration of emissions from stationary sources[5,6]. Therefore, at present the development of the experimental study of automotive pollution near highways and adjacent buildings is relevant along with the study of computational and theoretical methods to determine the concentration of harmful impurities of exhaust gases. Previous studies[1,5-7] demonstrate methods to forecast the air pollution produced by individual highways and groups of highways and present an analysis of predicted impurity concentrations in cities with different traffic intensity given different vehicle development scenarios in the city[6,8-11]. Roadside buildings affect the dispersion of exhaust gases and provide the flow of air from the surrounding highway areas. The higher the density of buildings, the less air they pass[4,5,7,12]. Total buildings density is regulated depending on the number of storeys. With the same number of storeys, the building composition may be different, thereby providing a local density. Therefore, when determining the concentration of pollutants from vehicles, one should take into account the number of storeys and a building composition. An analysis of references[1,2,5,8,13,14] shows that despite the large number of studies, methods and researches describing a pattern of dispersion and formation of harmful substances and exhaust gases. It is very difficult to take into account all factors that influence on the extent of air pollution in a particular area. Therefore, at present it is topical to develop and improve the ground-level concentrations calculation method that takes into account the influence of various factors on the nature of dispersion of pollutants near roadside buildings. Consequently, the study of the ecological situation and its formation in cities with roadside buildings requires further development and improvement.

The paper presents an experimental and computational study of air pollution in the city of Almaty, Astana, Shymkent, namely on the streets with the most intense vehicular traffic. Objective of the study is to study a consistent pattern of air pollution by road traffics given different types of urban buildings. According to the Department of Natural Resources and Environmental Management of the Republic of Kazakhstan, vehicles are a major source of air pollution in Almaty (over 80%), Astana (over 75%), Shymkent (over 70%), that is the highest value in the republic.

Main harmful substances in exhaust gases and in the air are nitrogen oxides NO_X (mixture of NO and NO_2) and carbon oxide (CO). Vehicles' contribution into the air pollution exceeds 60% of CO and 50% of NO_X in the total air pollution by these gases[2,3]. In view of the aforesaid, this paper presents results of the work to determine the concentration of these pollutants.

The experimental study of automotive pollution in residential areas was developed based on reliable information about the concentration of main components of exhaust gases given the traffic intensity, weather conditions, nature of an architectural structure. Study results presented in this paper may be useful for cities with a similar types of roadside buildings.

To achieve this objective, we have determined:

- Traffic intensity in city road intersections with the heaviest traffic in the rush hour;
- Types of urban buildings along highways;
- Weather conditions (wind speed, direction, ambient temperature). and have determined the following tasks:
- Assess the state of air pollution near road intersections with the heaviest traffic and near parking lots in different parts of cities;
- Study the dispersion of harmful impurities in residential areas with various types of buildings along a highway;
- Determine the impact of exhaust gases on the cities atmosphere.

EXPERIMENTAL

The study used the following methods: literature review, descriptive, mathematical and statistical methods.

The paper presents results of the work to determine the concentration of pollutants: nitrogen dioxide (NO_2) and carbon oxide (CO) in air samples collected from monitoring areas: near road intersections and parking lots in different parts of cities. Based on the road and street network scheme and the information about traffic loads in Almaty, Astana, Shymkent, that were provided by the State Automobile Inspectorate, we have identified road intersections with frequent jams and blocks as the most unfavorable road parts[15].

An analysis of air samples was conducted in accordance with regulatory documents, using certified methods and equipment listed in the Unified State Register of Measuring Tools of the Republic of Kazakhstan.

When determining nitrogen dioxide, air samples were collected in sorption tubes ST 2 or ST 3 with a film chemisorbent and were further analyzed by a photometric method with α- naphthylamine in accordance with regulatory documents[16].

When determining carbon oxide, air samples were collected in gas pipettes. Air samples were analyzed by an electrochemical method using the gas analyzer Palladium-3M in accordance with its operation manual and regulatory documents[16]. The analyzer was calibrated by a gas mixture of CO and "0" (purified nitrogen or air purified from CO).

The carbon oxide and nitrogen dioxide concentrations were measured on the territory adjacent to a highway in the rush hour (measurement time -7-8 to 10-11 a.m. and 4-5 to 7-8 p.m.) at different distances of 1, 25, 50, 100 m on both sides of the highway and at the height of 1 m. At the same time, we took into account the wind direction, speed, air temperature and humidity. However, in order to determine the impact of weather conditions a large number of field measurements is required for each season, which is a very complex and labor-intensive task. Therefore, as recommended by references[15,16], in order to collect an aggregate air pollution data, the monitoring was conducted in the rush hour in the warm season, namely from April to June 2014, for each substance: carbon oxide and nitrogen dioxide. At least 5 measurements were conducted in each monitoring area during the warm season, each measurement had 2-3 samples. The sampling was accompanied by the following procedures:

- Nitrogen dioxide: During the sampling the sorption tubes were installed with a sorbent layer down so that the air could pass through the sorbent layer upwards. Airflow of 5 dm^3 was blown through each ST at a rate of 0.25 dm^3/min. The selection of one sample was carried out within 20 minutes. Immediately after the sampling, the STs were plugged, wrapped with a black plastic film to protect from light and labeled. Properly plugged and wrapped STs were placed in a cooler (thermos) at + 2, + 4°C. Collected samples were delivered to a laboratory daily after the sampling.

- Carbon oxide: Gas pipettes of 250 dm^3 were connected to a aspirator channel by using a silicone hose. Airflow was blown at a rate of 20 dm^3/min within 13 mins. Air was aspirated through the gas pipettes to replace a 10-fold volume of air in the system so that to avoid the underestimation of concentration of analyzed substances. After a 13-min blowing, an electric aspirator was disconnected, and pipette stopcocks were closed. Selected samples were delivered to a laboratory in the gas pipettes sealed on two sides by stopcocks. For the purpose of sampling, we used the electric aspirator OP-442 TC that has passed an annual state verification.

Simultaneously with the sampling, we defined the meteorological characteristics of the environment:

- Wind speed and direction;
- Air temperature;
- Atmospheric pressure;
- Relative humidity;
- General weather conditions.

Each selected sample had a label with the name of the sampling area, the volume of blown air and the meteorological parameters at the time of the sampling. STs with sampled air were transported in a cooler at + 2, + 4°C. During the air sampling in an intersection of streets, we recorded the number of vehicles per unit of time (traffic intensity).

Due to the fact that at least 5 measurements were made in each area during the warm season provided that results of each measurement were averaged based on 2-3 samples. We present the average meteorological parameters for the air sampling. Assessment of air quality in the monitoring areas and a topographic reference were carried out with the use of a mobile office equipped with the sampling equipment to conduct the atmospheric monitoring and determine the meteorological parameters.

In order to study the air change conditions, we used a characteristic of the structure front line along highways. The structure openness factor A_{op} was applied as the characteristic representing the ratio of the projected area of gaps between buildings to the total projected area of front line against a highway red line.

A_{op} values are taken depending on the density of roadside buildings and a relative length of gaps between buildings (Table 1).

The relative length of gaps between buildings is determined from the formula (1):

$$\Delta l = 100\,(1 - \sum_{k=1}^{n} l_k / L_м)\,,\ \% \qquad \ldots(1)$$

where l_k – Length of facade or shorter side of k's house facing the highway

L_m – Length of highway section, m.

Table 1: The openness factor depending on the density of roadside buildings and the relative length of gaps between the buildings

Type of roadside buildings by density	Relative length of gaps between buildings Δl (%)	A_{op} value
Type 1: Very dense	10-19	0.59-0.71
Type 2: Dense	20-29	0.72-0.82
Type 3: Medium dense	30-39	0.82-0.90
Type 4: Low dense	40-49	0.90-0.97
Type 5: Free dense	50-60	0.97-1.00
Type 6: Open space	over 60	1.00

The necessary information about buildings along studied streets and near parking lots was obtained during their complex examination by measuring the length of the buildings and gaps between them provided that the length of the considered highway section was taken as 300 m:

- Type 1: Very dense, heavily built-up area with difficult air change (linear, line multi-storey buildings at a distance of less than 5-10 m from the highway;
- Type 2: Dense, built-up area with disrupted air change (linear, line, group multi-storey buildings at a distance of more than 10 m from the highway);
- Type 3: Medium dense, built-up area with an insignificant disruption of air change (line, group low-rise buildings at a distance of 7-10 m from the highway);
- Type 4: Low dense area with almost undisrupted air change (free low-rise buildings, open area with green space).

RESULTS AND DISCUSSION

Instrumental measurements of carbon oxide and nitrogen dioxide pollutants were used to identify the extent of pollution and the conditions of dispersion of harmful emissions from vehicles given a certain type of roadside buildings.

Table 2 shows relative length of gaps between the buildings, therefore, these areas are classified as relevant types of roadside buildings.

Table 2: Types of roadside buildings near given intersections and parking lots

Type of roadside buildings	L_M	Σl_k	Δl (%)	A_{op} value
Type 1: Very dense	300	264	12	0.61
Type 2: Dense	300	237	21	0.73
Type 2: Dense	300	225	25	0.77
Type 3: Medium dense	300	192	36	0.87
Type 4: Low dense	300	168	44	0.93
Type 4: Low dense	300	174	42	0.91

For the purpose of studying the influence of a certain type of roadside buildings on the pollution degree, we have analyzed concentration of pollutants at a distance of 1 m and 100 m from the highway (Table 3).

Table 3: Influence of the type of buildings on the dispersion of automotive pollutants

Type of roadside buildings	A_{op} value	CO conc. (mg/m^3)		Ratio of excess CO conc. (1 m/100 m)	NO_2 conc. (mg/m^3)		Ratio of excess NO_2 conc. (1 m/100 m)
		1 m	100 m (background conc.)		1 m	100 m (background conc.)	
Type 1: Very dense	0.61	6.140	5.020	1.22	0.290	0.156	1.86
Type 2: Dense	0.73	5.320	4.005	1.33	0.240	0.125	1.92
Type 2: Dense	0.77	6.010	4.530	1.36	0.270	0.130	2.08
Type 3: Medium dense	0.87	5.250	3.671	1.43	0.190	0.090	2.11

Cont…

Type of roadside buildings	A_{op} value	CO conc. (mg/m^3)		Ratio of excess CO conc. (1 m/100 m)	NO_2 conc. (mg/m^3)		Ratio of excess NO_2 conc. (1 m/100 m)
		1 m	100 m (background conc.)		1 m	100 m (background conc.)	
Type 4: Low dense	0.91	3.310	2.178	1.52	0.090	0.040	2.25
Type 4: Low dense	0.93	3.635	2.490	1.46	0.130	0.060	2.17

Concentrations of CO and NO_2 pollutants, which were obtained as a result of measurements conducted at a distance of 100 meters from the highway, are in the range of background concentrations permitted for cities. Therefore, values of these concentrations can be taken as background values for the given residential area. However, assumed values of background concentrations can be considered as such only conditionally, because the dispersion and transformation of these pollutants occur also outside of 100 m from the highway.

Based on the findings obtained, Fig. 1 shows the dispersion of pollutants as a ratio of excess CO, NO_2 concentrations at a distance of 1 m to 100 m, depending on the type of roadside buildings.

When analyzing the statistical series, we found that the relationship between the variables can be presented in the form of a third-order polynom with the following determination coefficients: R^2 = 0.9471 for CO, R^2 = 0.9579 for NO_2, and the following correlation coefficients: R = 0.9732 for CO, R = 0.9787 for NO_2:

$$C1co/C2co = -0,0038A^3 + 0,029A^2 + 0,0085A + 1,1967 \quad \ldots(2)$$

$$C1_{NO_2}/C2_{NO_2} = -0,0081A^3 + 0,0716A^2 - 0,0874A + 1,8833 \quad \ldots(3)$$

where C1co, $C1_{NO_2}$ – Concentrations at a distance of 1 m from the highway, mg/m^3;

C2co, $C2_{NO_2}$ – Concentrations at a distance of 100 meters from the highway, mg/m^3.

Table 4 shows the ratio of excess CO and NO_2 concentrations at different distances from the highway to determine the dispersive property of the relevant type of buildings in a monitoring area.

Diagrams show that the ratio of excess CO, NO_2 concentrations at distances of 1 m to 100 m becomes higher with the increasing openness factor (Fig. 1). Consequently, the low density of roadside buildings contributes to a better dispersion than in areas with more dense buildings.

As Table 4 shows, in a more built-up area the ratio of excess CO and NO_2 concentrations along the entire highway (1m to 100m) is less than in a medium- and low-density area. This indicates better dispersive property of areas with 3- and 4-type buildings and adverse environmental zones in 1- and 2-type zones. The exception is Rozybakiev Str. (Rakhat Market), which is likely due to its location at the bottom of the city, towards the dominant wind direction.

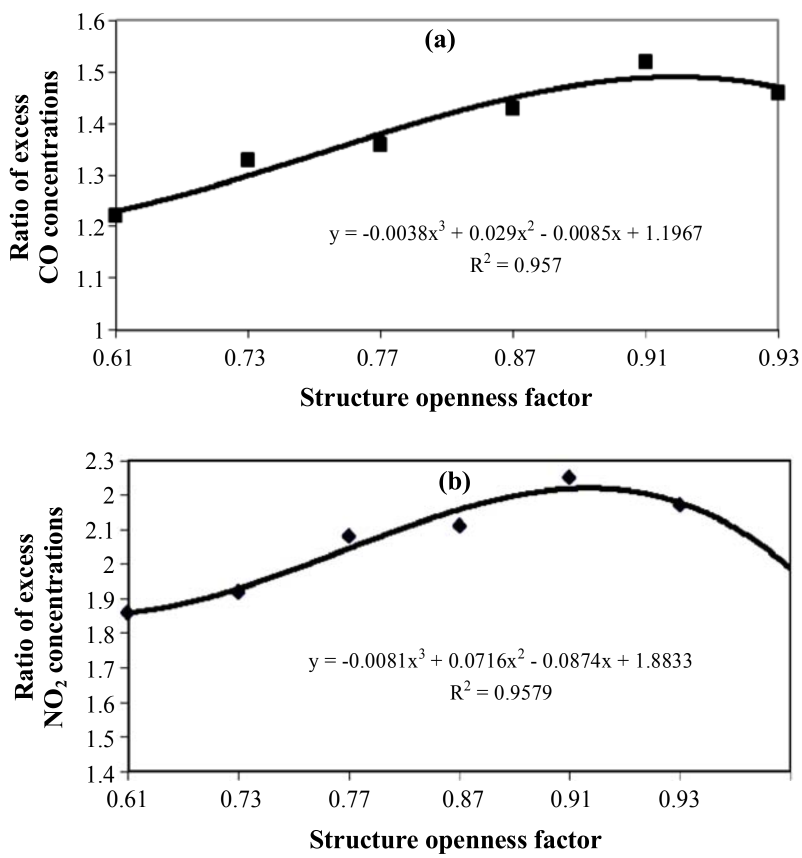

Fig. 1: Relationship between the ratio of excess concentrations at distances of 1 m to 100 m and the openness factor: (a) carbon oxide CO, (b) nitrogen dioxide NO_2

Table 4: The ratio of excess CO and NO_2 concentrations at different distances from highways

Type of roadside buildings	Conditional background conc., mg/m^3, at a distance of 100 m	Ratio of excess conc. 1 m/100 m	Ratio of excess conc. 25 m/100 m	Ratio of excess conc. 50 m/100 m
(a) Carbon oxide				
Type 1: Very dense	5.020	1.22	1.18	1.14
Type 2: Dense	4.005	1.33	1.25	1.20
Type 2: Dense	4.53	1.36	1.26	1.15
Type 3: Medium dense	3.671	1.43	1.39	1.35
Type 4: Low dense	2.178	1.52	1.48	1.34
Type 4: Low dense	2.490	1.46	1.24	1.16
(b) Nitrogen dioxide				
Type 1: Very dense	0.156	1.86	1.76	1.51
Type 2: Dense	0.125	1.92	1.72	1.48
Type 2: Dense	0.130	2.08	1.88	1.65
Type 3: Medium dense	0.090	2.11	1.72	1.44
Type 4: Low dense	0.040	2.25	2.38	1.86
Type 4: Low dense	0.060	2.17	1.83	1.5

CONCLUSION

The study of the influence of various types of roadside buildings on the dispersion and the concentration of CO and NO_2 pollutants enabled us to draw the following conclusions:

(i) The highest concentration of automotive pollutants is observed near highways with 1- and 2-type roadside buildings, that is in the most build-up and closed areas (Table 3).

(ii) Based on the ratio of excess concentrations we have found that in the course of the dispersion of studied pollutants the reduction rate of nitrogen dioxide concentration is higher (by 2.1 times on average) than the reduction rate of carbon dioxide concentration (by 1.4 times on average). Given this, we can assume unfavorable accumulation of carbon dioxide in the surface atmospheric layer in roadside areas.

(iii) Based on the ratio of excess concentration at distances of 1 m and 100 m from the highway, we have found that a high density of roadside is inversely proportional to the dispersion of pollutants, i.e. contributes to their accumulation near emission sources.

In order to protect the atmospheric air from automotive pollution, it is necessary to take the city-planning measures to reduce the concentration of exhaust gases in the human habitation area. They include special construction patterns, landscaping of highways and zonal construction of residential buildings as follows: low-rise buildings should be constructed in the first line from the highway, then high-rise buildings, and children and health-improving facilities should be constructed in the very heart of the buildings. Sideways, residential, commercial and public buildings should be isolated from the highway with heavy traffic by a multi-row planting of trees and bushes, in three or four rows or more. The construction of transport interchanges at different levels and ring roads, as well as the use of underground space for parking lots and garages are of high importance. Implementation of these measures will reduce the traffic intensity and noise from automotive sources.

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