INVESTIGATION OF THE CIRCUMSTANCE OF THE LIGHT-SIGNALS INFLUENCE UPON THE HARMFUL SUBSTANCE CONCENTRATIONS DISTRIBUTION BY NUMERICAL MODELLING

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Abstract

Using mathematical modelling, harmful substance concentration distribution in Tbilisi, at certain crossroad, where traffic is congested, and for the whole territory adjoined to the crossroad have been studied. Also influence of traffic-lights on the harmful substances concentrations growth have been investigated.

1 Introduction

At present industrial potential of Georgia is very low, as many existing plants and factories are not functioning. For this reason, exhaust gases represent main air pollutants in the country. Therefore, air pollution is on the high level in Tbilisi, capital of Georgia, with population of 1.5 million. Reasons and results of Tbilisi air pollution is not much different from any urban area in the world. Aerosols are considered as one of the main air pollutants in Tbilisi. As known, air pollution in urban areas due to traffic is much higher in rush-hours. Exhaust gases, which mainly consist in nitrogen oxides, have very adverse effects on human health, besides bad environmental changes. According to official statistical data of Georgia, air pollution in urban areas with heavy traffic is higher than in industrial areas. It is expected, that the continuous economic growth will strengthen the traffic intensity, therefore quality of air will worsen. Unfortunately, for the last 15 years, owing to difficult economic situation and lack of financing, system of meteorological and observation stations have almost been destroyed in Georgia. Now there are functioning only six meteorological observation laboratories in Tbilisi from 34 existing in 1992. Besides, Tbilisi has rather compound orography. Thus, investigation of dispersion of

exhaust gases in the main Tbilisi streets, by means of mathematical modelling is very important for human health, environmental management and future economic planning, including revising of street network and traffic management.

2 Materials and methods

Amount of vehicle exhaust and content of main harmful substances in gas, such as carbonic acid (CO), nitric acids (NO_x) and hydrocarbons (C_xH_x), depend on the traffic intensity, vehicle type and speed, road width and the number of traffic lines. On the given lengthwise layer in the given time unit, exhaust amount is calculated by the following formula ([2]):

$$M = a\Sigma Q_i * \Pi_i * N_i, \tag{1}$$

where M is an exhaust of the harmful substance (gr/sec. km) per 1 km; $a = a\rho$; ρ is average density of fuel (≈ 0.74kg/l.); $a' = 1000$grhr/(3600kghr); $a \approx 0.2$; N is the traffic intensity (number of vehicles, passing the given lengthwise layer in given time unit (hr^{-1})); Q is the amount of the petrol consumed by the vehicle per one km (l/km); Π is un-dimensioned coefficient, expressing the correlation of the harmful exhaust to consumed petrol; n is the number of the cars of different types. If we pick out cars, buses, microbuses and lorries, then from Eq. (1) we will have:

$$M = 0.2[(Q*\Pi*N)_{cars}+(Q*\Pi*N)_{buses}+(Q*\Pi*N)_{micbuses}+(Q*\Pi*N)_{lorries}],$$

where $Q_{cars} = 0.11$, $Q_{buses} = 0.35$, $Q_{mic-buses} = 0.18$, $Q_{buses} = 0.31$. N_{cars}, N_{buses}, $N_{mic-buses}$, N_{lor}. are determined by experimental observations. As it is recommended ([2]) $\Pi_{NOX} = 0.04$, $\Pi_{CXHX} = 0.1$, it doesn't depend on the speed and $_{co}$ depends on the average speed, namely: $\Pi_{co}(20) = 0.72$, $\Pi_{co}(30) = 0.6, \Pi_{co}(40) = 0.45$, $\Pi_{co}(50) = 0.22$, $\Pi_{co}(80) = 0.16$. CO, NO_x exhaust from the cars with diesel engine is several times less than from the cars with petrol engine, although it's difficult to determine in our conditions. The existence of the crossroads has a definite influence on the concentration of the exhausted substance, that can be represented by the following mathematical dependence:

$$C_{crossroad} = C_o(1 + N_2/N_1), \tag{2}$$

where C_o is the maximum concentration caused by the exhaust on the observed main arterial road. N_1 and N_2 indicate the intensity of the traffic for the given main and crossroads, respectively. The fulfillment of the experimental activities, provided by the given method includes the following

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stages: 1) determining the average typical structure of the motor transport stream; 2) determining the intensity of the roads; 3) determining the average value of the intensity of the traffic by the formula: $N_{aver.} = 1/3$ $(N_{morning}+N_{noon}+N_{evening})$. The method of researching of atmospheric air pollution by motor transport is based on the well-known and tested different physical and mathematical models ([1], [3]), which approximately represent the dynamics and mechanism of such processes. Namely, this method is based on solving the system of three-dimensional differential equation of non-stationary turbulent boundary layer ([5], [4]). The temperature and wind regime of the lower layer of the atmosphere, where the main mass of the polluting components lies, depends on the processes of synoptic scale (advection, vertical movements) as well as on the boundary layer processes (turbulence, radiation). In our model the influence of the broad-scaled factors, determined by means of the background meteorological fields (wind velocity, temperature and harmful substances concentrations), is regarded as external parameters. In this model we assume, that the wind is uniform on the horizontal plane and changes on height, but density and pressure dependant only on height. Also there is inflow of the harmful substances in the considered region. It is necessary to take into account relief, when we examine the problem of transference and diffusion of adverse substances for the street network, as landscape of Tbilisi is in-homogenous enough, and street network of the city mainly is not arranged. That is way the numerical model has taken into account orography of examined region of Tbilisi ([4]). The numerical modeling is realized in the domain $1000m * 1000m * 1000m$ using well known scheme by F. Shuman. The space-temporary numerical grid consists $500 * 500 * 200$ points. The steps of the grid along axes x and y are equal to $2m$. The step of the grid along axis z is equal to 5m and on time $0.1s$.

3   Results and discussion

We have learnt spreading of harmful substances on the intersection of Agmashenebeli and King Tamar Avenues. On Agmashenebeli Avenue the intensity of the traffic was approximately 3000 cars per hour, and on King Tamar Avenue - 3600 cars per hour. The traffic intensity of the different type cars on Agmashenebeli and King Tamar Avenues is distributed as follows: Agmashenebeli Avenue -:$N_{pass.} = 0,38$; $N_{mic.} = 0,40$; $N_{bus.} = 0,05$. King Tamar Avenue - $N_{pass.} = 0,53$; $N_{mic.} = 0,38$; $N_{bus.} = 0,06$. As it was expected, the highest concentration level was at the streets' intersection, which exceeded the Maximum Permissible Concentration of the day 2.2 times - up to $0.09gr/m^3$ (here and further is meant concentration of

harmful substance NO_x). With the growing distance from crossroad along the streets, amount of pollution was falling (from 0.08 to 0.4). The concentrations were relatively low at the outskirts territories - from $0.02gr/m^3$ to $0.03gr/m^3$. High concentrations were observed in the neighborhood of the crossroad, at the south side of King Tamar Avenue and at the east side of Agmashenebeli Avenue. In addition, results of calculations have shown, that after the motor transport was stopped for ten minutes, the concentrations distribution was radically changed. Level of pollution grows from $0.06gr/m^3$ to $0.08gr/m^3$ from south-east to north-west direction, because transfer of harmful substances was conditioned by the wind direction. As pollution level radically decreased, we may conclude that during ten minutes the harmful substances were conditionally transferred out of the territory's borders. We have also studied influence of light-signals in the streets on the distribution of harmful substances. There are light-signals at four angles of King Tamar and Agmashenebeli Avenue crossroad and there working cycle is 35 seconds. During this time, vehicles accumulate at the both sides of the streets, which consequently leads to the growth of gas masses. The accumulation of cars reaches the average maximum distance of 200 meters away from the intersection. Consequently, in this radius, the growth of unhealthy gas depends on the traffic intensity at the present moment. In our case the concentration grew approximately 2 times ($0.19gr/m^3$.). We have studied the distribution of harmful substances concentration not only for the separate streets, but also for the whole complex of adjoined territories (fourteen districts). We have studied the intensity of transport movement in these streets of Tbilisi, which gave us the following figures: Agmashenebeli Avenue: 3000 cars per hour; King Tamar Avenue: 3600; Tsinamdzgvrishvili St.: 1200; Ninoshvili St.: 600; Potskhverashvili St.: 300; Konstitution St.: 1000; Kargareteli St.: 400. The intensity of movement among different types of cars are distributed in the following way: Tsinamdzgvrishvili St.-$N_{ms} = 0.48$; $N_{mic} = 0.45$; $N_{bus} = 0.07$. Konstitution St.-$N_{ms} = 0.65$; $N_{mic} = 0.30$; $N_{bus} = 0.05$. For Agmashenebeli and King Tamar Avenues these significances are given above, for the rest streets the significances are: $N_{ms} = 0.77$; $N_{mic} = 0.19$; $N_{bus} = 0.04$. By putting the received facts into Eq. (1), we have got the harmful substances masses as a result of transport unhealthy gas. With the help of the given harmful substances masses, we have established the harmful substances concentrations' initial significance at the ground surface. By using the received significances and by using Eq.(2) and the stated above mathematical model, we have studied the distribution of harmful substances concentration at the indicated territory. It is implied that at the initial time period, the motor transport begins moving with the maximum intensity. Such an intensive movement continuous for an hour, after which the

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movement radically ceases and after which we observe the distribution of gathered harmful substances concentrations at the streets' adjoined territory. At the initial time period the wind vector is turned to the south-east direction and its speed grows in accordance with height from 0 to 5 m/c, and it reaches the maximum significance at Z=600 meters height. Calculations have shown that the wind vector's influence on harmful substances' concentration distribution is clearly seen. The concentration distribution monotonously increases from north-west to south-east direction at the limits from $0.08gr/m^3$ to $0.12gr/m^3$. which was caused by motor transport intensity, presence of the light-signals and the wind vector's direction.

4 Conclusions Calculations have shown that the wind vector has influence on harmful substances' concentration distribution. The concentration distribution monotonously increases from north-west to south-east direction in Tbilisi. Existence of the light signals made a great effect on the concentration distribution at the territory in the radius of $250 - 300m$ from Agmashenebeli and King Tamar avenues intersection, at the places, where traffic is congested. As the distance from this point grows, concentration gradually decreases. Existence of light-signals also increased the harmful substances concentration approximately 2 times. Taking as a basis this experimental calculations, we conclude that the growth of harmful substances wholly depends on the traffic intensity as well as on the light-signal's placement and working cycle.

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