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REDUCING THE NEGATIVE IMPACT ON THE ENVIRONMENT THROUGH ORGANIZATION OF TRAFFIC FLOWS CONSIDERING THE EMISSIONS OF INDUSTRIAL ENTERPRISES

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ABSTRACT

Within the research work the authors carried out analysis of the air pollution sources in the city of Naberezhnye Chelny and conducted field examinations of the traffic flow structure and density on the city highways. The highway segments with polluting agent concentrations exceeding the sanitary and hygienic standards were identified, as well as emission allowances on the polluting agents from motor vehicles were determined, considering also the emissions of industrial enterprises. To solve the problem on reducing the emissions of polluting agents to the specified level, the authors developed a simulation model that is able to consider a large number of the road network parameters. An optimization experiment was conducted that enabled to determine emission allowances through the optimization of the traffic flow speed, density and intensity.

Keywords: atmospheric air, polluting agents, vehicles, emission allowances.

1. INTRODUCTION

The urban environment is exposed to intense pollution by a broad range of toxic agents, whose main sources are industrial enterprises and motor vehicles. While an industrial enterprises are located usually outside of populated localities, have specified regulatory allowable emissions, are provided with gas purification plants, mobile sources are concentrated in inhabited localities, creating an unfavorable environment.

The situation with cities air basins pollution by auto-transport is aggravated by the conditions of aeration of populated areas, which determine the process of polluting agents dispersion. It differs significantly from the dispersion of polluting agents emissions from stationary pollution sources. Auto-transport emissions of polluting agents into the lower atmosphere result in high level of their surface concentrations. The maximum content of polluting agents is fixed at the height of 50-200 cm from the ground surface, i.e. is located in the breathing zone of a human. The level of concentration of nitrogen oxides, carbon and other harmful ingredients on the streets of Russian cities is 10-20 times higher than the maximum permissible concentration (MPC) [1, 2, 3, 4]. The low intensity of the self-purification processes of the atmosphere in the near-surface layer leads to the sorption of the combustion products by the soil surface, snow cover and greenery on the territories adjoining to roads. Heavy metals, deposited mainly along highways, create "dead zones" with the width of 120 m along both sides of the highway, and up to 400 m at the intense traffic (over 10 thousand vehicles per day) [5, 6, 7, 8, 9, 10, 11, 12, 13, 14].

2. METHOD

Specific emission of the i-th polluting agent (g/s) by moving traffic flow on the respective segment of the motorway with a fixed length L (km) is determined by the formula:

$$M_{Li} = \frac{L}{3600} \cdot \sum_{1}^{k} M_{k,i}^{n} \cdot G_k \cdot r_{V\,k,i} \tag{1}$$

where $M^{n}_{\kappa,i}$ (g/km) – is the specific emission of i-th harmful substance by cars of k-th group for urban conditions; k – is the number of vehicle groups; G_k (1/h) – is the actual greatest traffic intensity, i.e. the number of vehicles of each of k groups, passing through a fixed cross section of the selected motorway segment per unit time in both directions in all lanes; 1/3600 – is the conversion factor to recalculate hours into seconds; L (km) - is the length of motorway (or motorway segment); $r_{V\,k,i}$ – is the correction factor which takes into account the average speed of traffic flow (v_k, km/h) on the selected highway.

Specific emission of the i-th polluting agent (g/s) for the traffic flow in the controlled intersection zone is determined by the formula:

$$M_{\Pi i} = \frac{R}{3600} \cdot \sum_{n=1}^{N_c} \sum_{\kappa=1}^{Ng} (m_{ik}^{q} \cdot Q_{\max}^{k}) \tag{2}$$

where R – is the average duration of red light, *min* (including interstitial time); $N_{ц}$ – is the number of red light cycles within a 20 minute period of time, *units*; $N_{гг}$ – is the number of vehicles groups; m_{ik}^{q} – is specific emission of i-th polluting substance by the vehicles of *k-th* group, staying “in queue” at the red light, g/min; $Q_{\max}^{k}$ – is the length of the vehicles “queue” of k-th group, staying in the intersection area at the end of the n-th cycle of red light.

Emissions of polluting agents from stationary sources are determined by data collection of projected

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maximum permissible emissions and industrial control of enterprises.

The concentration of polluting agents is calculated using standardized program "Ecologist". The highest values of the total concentration of harmful impurities C_m (mg/m^3) is determined by the following formula:

$$C_{м} = \frac{AMFm'\eta}{H^{7/3}} \tag{3}$$

where A – is the coefficient dependant on temperature stratification of the atmosphere; M – is the mass of harmful substance emitted into the atmosphere per unit time (g/c), in case of traffic flow it is the mass of polluting agent, emitted by the group of vehicles, forming traffic flow; F – is dimensionless coefficient, taking into account the rate of gravitational sedimentation of particulate matter (dust) in ambient air to the underlying surface (at the calculations of soot dispersion in the atmosphere from the mobile vehicles engines, it is recommended to take the value of the parameter F=1); m' – is the dimensionless coefficient, equal to 0.9; η – is the dimensionless coefficient, taking into account the topography, equal η=1 for smooth or mild terrain with elevation change not exceeding 50 m per 1 km; H – is the height of the highway above ground level, as fugitive source of emissions.

Emission allowance is determined by the total specific emission of i-th polluting agent from vehicles and stationary sources, at which concentration at the point corresponding to 1 MPC, is not exceeded, while for the sanitary protection areas of resorts, rest houses, city rest areas and other zones with strict requirements to air protection this limit is 0.8 MAC [15, 16, 17, 18, 19, 20].

$$M_{кв,i} = \frac{C_{м,i(пр.)} + C_{м,i(авт.)}}{ПДК} \leq 1 \tag{4}$$

3. RESULTS

Based on the data obtained, the authors have performed a summary calculation of 143 polluting substances dispersion, including those forming the 28 summation groups. When performing calculations, the influence of weather conditions and the effect of terrain on the distribution of impurities was taken into account. The calculations allowed obtaining the patterns of air pollution levels throughout the city of Naberezhnye Chelny. A map of the spatial distribution of carbon monoxide is presented in Figure-1.

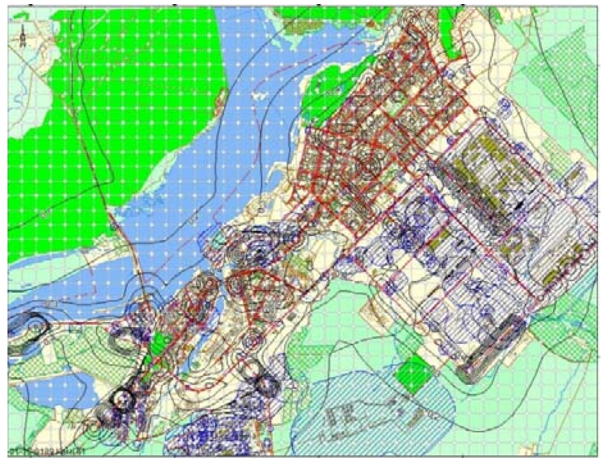

Figure-1. Dispersal map of carbon monoxide.

Based on the results of the polluting substances dispersion, the authors predicted their concentrations in the residential area of the city and identified the polluting agents and summation groups, for which the exceedance of MPC is the most probable.

The authors defined the road segments with a concentration of polluting agents, exceeding the sanitary-hygienic standards, and determined the optimal amount of polluting agents in emissions from vehicles, considering also the emissions of industrial enterprises.

To solve the problem on reducing the polluting agent emissions to the specified level, the authors developed a simulation model that is able to consider a large number of the road network parameters, including those of probabilistic nature.

The model is implemented in the simulation environment of the Russian software developer AnyLogic. Figure-2 shows a diagram of the most problematic road junction in the city of Naberezhnye Chelny. This hub is characterized by high intensity of traffic flows that cause, as a consequence, traffic jams and congestion.

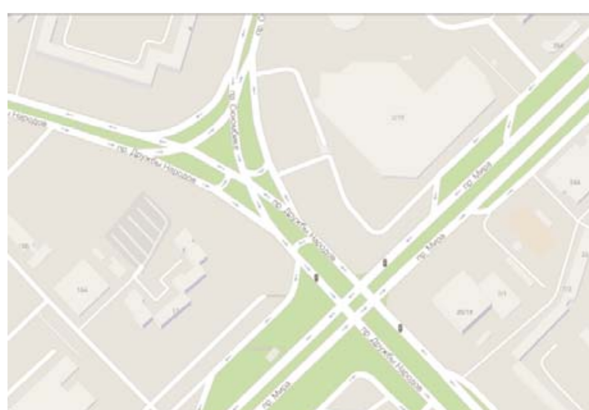

Figure-2. The road junction diagram.

Structural diagram of the model on traffic flow management is presented in Figure-3. This diagram incorporates elements of the road traffic library (Road

Network, CarSource, CarDispose, and CarMoveTo), as well as elements of the basic library (Hold, Delay, Queue, and SelectOutput). A Java class "Car" was employed to simulate the behavior of vehicles on the road.

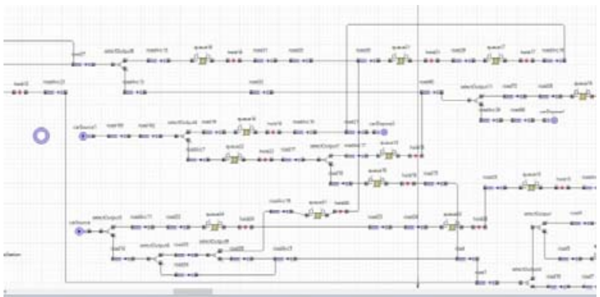

Figure-3. A diagram of the vehicle traffic flow management considering emission allowances of polluting agents.

The maximum speed of vehicles, the speed at turns and U-turns, maximum and minimum inter-vehicle distance, alerting distance about intended maneuvering, and the time needed for maneuvering are defined in “Road Network” block. In addition, the change in traffic speed on different road segments is taken into account, wherefore the speed value is set in “Move Car To” block. Generation of a traffic flow is carried out in “Car Source” blocks.

The vehicles traffic in the model is carried out in accordance with motion parameters embedded in the “Move To Car” blocks. To distribute the traffic flow in different directions the “Select Output” blocks are employed. The “Queue” blocks are used for modeling queues of vehicles at traffic lights, intersections and U-turns. The “Hold” blocks are used to simulate the traffic light and traffic control of vehicles on the turns and U-turns. The modeling of public service vehicles is carried out through “Delay” blocks, which allow setting the delay time of public transport at stops. Also to control the traffic lights and traffic flow the state diagrams are used.

The simulation model was used to conduct an optimization experiment with the use of OptQuest mechanism, which is based on metaheuristic methods. This experiment allowed determination of the preferred traffic flow parameters (density, intensity and speed), at which the emission volumes of polluting substances do not exceed the emission allowances. Seven hundred iterations were carried out during the optimization process. The best value of the objective function was determined at 451st iteration.

4. CONCLUSIONS

In the framework of the current study the information on existing stationary sources of air pollution is collected and analyzed, as well as their qualitative and quantitative characteristics. Counting campaign to determine the structure and intensity of the moving vehicular flow on the main highways of Naberezhnye Chelny was carried out. Based on the dispersion calculations results of polluting substances from traffic flow and industrial enterprises, the authors established emission allowances for emissions of polluting agents by road transport, considering also the emissions from industrial enterprises. A simulation model, enabling one to take into account the different parameters of road traffic flows, including stochastic ones, was created. The model was implemented in the AnyLogic simulation environment. Using this software product, the preferred traffic flow parameters, such as density, intensity, and speed, at which the total emission volumes of polluting substances do not exceed the emission allowances, were identified.

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