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ЕКОЛОГІЯ ТА ПРОМИСЛОВА БЕЗПЕКА

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M. M. BILIAIEV[1*], T. I. RUSAKOVA[2*]

[1*]Dep. «Hydraulics and Water Supply», Dnipro National University of Railway Transport named after Academician V. Lazaryan, Lazaryan St., 2, Dnipro, Ukraine, 49010, tel. +38 (056) 273 15 09, e-mail water.supply.treatment@gmail.com, ORCID 0000-0002-1531-7882
[2*]Dep. «Aerohydrodynamics and Masstransfer», Oles Honchar Dnipro National University, Kazakov St., 18, Dnipro, Ukraine, 49010, tel. +38 (056) 776 82 05, e-mail rusakovati1977@gmail.com, ORCID 0000-0001-5526-3578

DETERMINING ZONES OF CHEMICAL POLLUTION IN THE CITIES AND ASSESSMENT OF CHRONIC DISEASES RISKS

Purpose. The scientific paper is aimed at creating a methodology of chemical pollution zones in the territories of industrial cities and accounting the possibility of assessing the risks of chronic diseases. **Methodology.** The method of numerical calculation of nitrogen dioxide concentration in atmospheric air is based on the solution of three-dimensional impurity transfer equations, which directly comes from a permanently stationary source (industrial enterprise) and a linearly distributed source (highway). The method takes into account the process of chemical transformation of impurities and photolysis in the atmosphere. The numerical model is based on the splitting of model equations and their solution using an implicit difference scheme. **Findings.** The created software allows conducting computational experiments to calculate the areas of atmospheric air pollution with nitrogen dioxide, taking into account the interaction of impurities coming from various types of pollution sources and meteorological para meters. On the basis of the obtained field of nitrogen dioxide concentration, an assessment of the change in the risk of chronic intoxication associated with atmospheric air pollution with nitrogen dioxide over 50 years was carried out. **Originality**. For the first time the regularities of changes in the level of atmospheric air pollution with nitrogen dioxide have been established with due regard to the mutual influence of emissions from the industrial enterprise and highway and their chemical transformation in the atmosphere. The risk of chronic intoxication has been calculated and its changes have been analyzed with due regard to the interaction of emissions from the industrial enterprise and highway, it leads up to 10% of risk increasing. **Practical value.** Authors developed a mathematical model and method of numerical calculation. Software created on their base allows obtaining quickly quantitative results necessary in developing the system for monitoring the man-made loaded regions of the city. The obtained patterns of impurities dispersion allow us to estimate the levels of pollution in urban areas of the city by emissions from industrial enterprises and highways. Accounting of the mutual impact of emissions and the calculation of risks of intoxication allows solving environmental problems arising in the development of transport strategy in cities.

Keywords: industrial enterprise; highway; dispersion of impurities; chemical interaction; risk of disease

Introduction

The atmospheric air of the territories in large cities contains a large amount of anthropogenic impurities: emissions from industrial enterprises, motor vehicles, mini-boiler houses, products of fuel combustion and waste incineration. These impurities are characterized by a constant presence in space, inhomogeneity and uneven distribution. The growth of motor vehicles retains its leadership in urban air pollution, in contrast to emissions from stationary sources, which tend to be sustainably reduced.

For mobile sources of pollution (cars) are characterized: by high rates of growth in the number of cars compared with an increase in the number of stationary sources; their spatial distribution; close proximity to residential areas; higher toxicity of vehicle emissions compared to stationary sources; low location of the source of pollution from the earth's surface, as a result of which the exhaust

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gases of automobiles accumulate in the breathing zone of people and are dispersed more slowly by wind compared to industrial emissions. These features lead to the fact that motor transport creates extensive zones with a steady excess of air pollution standards in cities.

The constant increase in emissions of nitrogen oxides into the air is also connected: with the development of motor transport, tendency of more complete use of fuel, which leads to an increase in *NOx* emissions with increasing temperature at more efficient engine operation; with an increase in the speed of the motor transport, as a result of which *NOx* grows nonlinearly. In this regard, anthropogenic pollution of atmospheric air with nitrogen oxides takes on a critical character in industrial densely populated cities with a large network of highways.

According to the data of the environmental passport of Dnipro city, the main stationary industrial sources of air pollution with *NOx* emissions include several city enterprises (Table 1).

Table 1

The *NOx* emissions of the main enterprises of the city

Name of the property	Total *NOx* emissions, t/year	To the total object emissions, %	To the total emissions (settlement) of the object, %
Prydniprovska TEPS	15 399.971	18.7	84.3
PC «Dnipro Metallurgical Complex»	4 003.362	3.7	62.2
PLC «Dnipro Metallurgical Plant»	1 066,608	11.9	5.8
PC «Interpipe Nyzhnodniprovskyi Tube Rolling Plant»	437.807	28.6	2.4
PLC «Dnipro Coke Chemical Plant»	413.750	32.7	4.1

Analysis of the data of the Central Statistical Office in the Dnipro region showed that the total amount of *NOx* emissions from all stationary sources of pollution in the Dnipro city was about 50.000 tons, and from all types of vehicles about 20.000 tons in 2017.

The peculiarity of air pollution in industrial cities is that there is an interdependence of emissions from various types of sources. The most typical situation is the interaction of emissions from industrial enterprises with emissions from motorways (Fig. 1). The assessment of the pollution level taking into account the emissions interaction is rather difficult task, both from a mathematical point of view and in numerical implementation. The complexity is due to the need to solve the three-dimensional mass transfer equations for impurities that enter the atmosphere from various types of pollution sources, as well as the need to take into account the processes of chemical transformation of impurities in the atmosphere.

When solving this class of problems, studies are carried out to find changes in the concentration in the atmospheric air of impurities received either from stationary sources or from mobile ones with or without consideration of the process of their chemical transformation in the atmosphere [2].

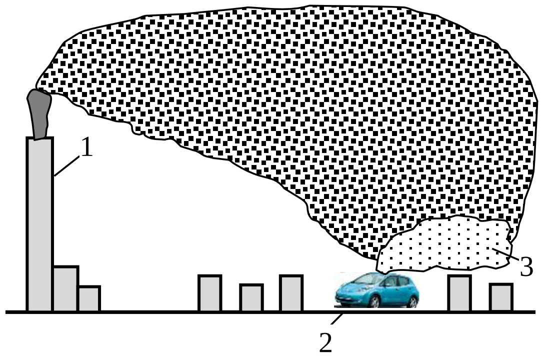

Fig. 1. Scheme of emissions influence:
1 – industrial facility; *2* – the highway;
3 – zone of mutual influence of emissions from *1* and *2*

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Both abroad and in Ukraine, calculations are carried out on the basis of empirical or analytical models or on the basis of numerical models of software packages [10–15]. In these works, a number of factors affecting the state of the atmospheric air of the city are considered; effective methods for reducing the man-made load are proposed. Mathematical modelling of the space-time distribution of pollutants from a power plant, which is performed in the FlexPDE software package, is studied in [11]. The efficiency of a system for modeling air pollution and human exposure was estimated on the base of the geographical information system AirGIS [7]. The effect of emission sources on environmental pollution $PM_{2.5}$ [8, 14] has been considered. Background pollution represents the lowest levels of air pollution to which people are constantly exposed, but few studies have focused on modeling this type of pollution [9].

However, the question of the mutual influence of impurities from industrial emissions and highways, while taking into account their chemical transformation in the atmosphere, remains relevant.

In industrial cities, the forecast of risks for the population is of great importance. Risk assessment in case of technogenic accidents is the subject of works by V. I. Golinko, L. V. Drannikova, V. F. Stoetsky [3], works on risk analysis in case of systematic air pollution with hazardous chemicals are dealt with by V. V. Menshikova, A. A. Shvyryaeva, T. B. Zakharova [5], chemical transformation processes are described in H. T. Overman [13]. Obviously, where there is an interaction of impurities of various types of sources (Fig. 1, zone 3), the risk of the disease increases even more, since the residents of this region may not suspect that they are in the zone of influence of several sources of air pollution. You can identify zones on the city map and assess possible risks using mathematical modeling methods. This issue is also important from the point of view of the monitoring system of technologically loaded regions.

Metallurgy is one of the most important sectors of the economy, as it allows other industries to develop. PC «Interpipe Nyzhnodniprovskyi Tube Rolling Plant» is the largest manufacturer and supplier of steel pipes for various purposes; the products of this plant are supplied to 50 countries of the world, characterized by high reliability and durability. However, this company has a technological impact on the air, it is among the environmentally-unsafe objects located in the city.

The emissions of nitrogen oxides from «Interpipe Nyzhnodniprovskyi Tube Rolling Plant» are considered, which, according to statistical data, amount to 437.807 tons/year (Table 1). This industrial enterprise occupies an intermediate position among other enterprises of the city in terms of *NOx* emissions, which allows evaluating the mutual influence of emissions from this enterprise and the nearby highway with certain traffic intensity.

Purpose

The main purpose of this research is to develop a mathematical method of numerical calculation for estimating the concentration of impurities in the atmospheric air of a city with the mutual influence of emissions from an industrial enterprise and vehicle emissions taking into account their chemical transformations in the atmosphere and meteorological parameters, on the base of three-dimensional transport equations. On the basis of the received field of *NOx* concentrations, it should carry out an assessment of the risks of chronic intoxication of the population living in the area affected by the selected sources of pollution.

Methodology

When a vehicle is moving and when it is idling, various kinds of pollutants enter the air, which undergo a transformation under the influence of sunlight. Let us consider the main chemical reactions occurring in atmospheric air between nitrogen oxide NO, nitrogen dioxide NO_2 and ozone O_3 :

$$NO_2 + h_\nu \xrightarrow{J} NO + O, \quad (1)$$

$$O + O_2 \rightarrow O_3 \quad (2)$$

$$NO + O_3 \xrightarrow{k_1} NO_2 + O_2, \quad (3)$$

Only the main three reactions (1) – (3) are taken into account, since to calculate the chemical transformation of emissions in the atmosphere, it is necessary to know the rates of their chemical reactions, which are determined experimentally. They were studied in papers [12–13].

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To calculate the level of air pollution by these pollutants, it is necessary at the first stage to solve the transport equations for each impurity in the atmosphere:

$$\frac{\partial[NO]}{\partial t}+\frac{\partial u[NO]}{\partial x}+\frac{\partial v[NO]}{\partial y}+\frac{\partial w[NO]}{\partial z}=$$

$$=\frac{\partial}{\partial x}(\mu_x\frac{\partial[NO]}{\partial x})+\frac{\partial}{\partial y}(\mu_y\frac{\partial[NO]}{\partial y})+$$

$$+\frac{\partial}{\partial z}(\mu_z\frac{\partial[NO]}{\partial z})+$$

$$+Q_{NO}\delta(x-x_0)\delta(y-y_0)\delta(z-z_0)\,; \quad (4)$$

$$\frac{\partial[NO_2]}{\partial t}+\frac{\partial u[NO_2]}{\partial x}+\frac{\partial v[NO_2]}{\partial y}+\frac{\partial w[NO_2]}{\partial z}=$$

$$=\frac{\partial}{\partial x}(\mu_x\frac{\partial[NO_2]}{\partial x})+\frac{\partial}{\partial y}(\mu_y\frac{\partial[NO_2]}{\partial y})+$$

$$+\frac{\partial}{\partial z}(\mu_z\frac{\partial[NO_2]}{\partial z})+$$

$$+Q_{NO_2}\delta(x-x_0)\delta(y-y_0)\delta(z-z_0)\,; \quad (5)$$

$$\frac{\partial[O_3]}{\partial t}+\frac{\partial u[O_3]}{\partial x}+\frac{\partial v[O_3]}{\partial y}+\frac{\partial w[O_3]}{\partial z}=$$

$$=\frac{\partial}{\partial x}(\mu_x\frac{\partial[O_3]}{\partial x})+\frac{\partial}{\partial y}(\mu_y\frac{\partial[O_3]}{\partial y})+$$

$$+\frac{\partial}{\partial z}(\mu_z\frac{\partial[O_3]}{\partial z})\,, \quad (6)$$

where Q_{NO} is the intensity of NO emission from the industrial enterprise or transport, Q_{NO_2} is the intensity of NO_2 emission from an industrial enterprise or from motor transport; *u*, *v*, *w* – components of the wind speed vector; $\mu=(\mu_x,\mu_y,\mu_z)$ – turbulent diffusion coefficients; x_0, y_0, z_0 – coordinates of the emission source of the pollutant (industrial plant or highway); $\delta(x-x_0)\ \delta(y-y_0)\ \delta(z-z_0)$ – Dirac delta function, which is used to simulate the release of a pollutant. The values of diffusion coefficients are calculated using the formulas: $\mu_x=(0{,}1\div1)\cdot U$, $\mu_y=(0{,}1\div1)\cdot U$, where U is the wind speed, $\mu_z=k\left(\frac{z}{z_1}\right)^m$, where z is the height above the level of Earth, z_1 is the height where the wind speed is U, $m\approx1$, $k=0{,}2$ [4, 6].

At the second stage, it is necessary to calculate the chemical transformation of impurities. The process of chemical transformation is calculated on the basis of dependencies:

$$\frac{d[NO]}{dt}=-k_1[NO]\,[O_3]+J_{NO_2}[NO_2], \quad (7)$$

$$\frac{d[NO_2]}{dt}=-k_1[NO]\,[O_3]-J_{NO_2}[NO_2], \quad (8)$$

$$\frac{d[O_3]}{dt}=-k_1[NO]\,[O_3]+J_{NO_2}[NO_2]. \quad (9)$$

Chemical reactions and photolysis are interrelated in the atmosphere. The photolysis rate J_{NO_2}, [s^{-1}] and reaction rate constant k_1, [ppb^{-1}s^{-1}], depending on temperature, are determined by expressions:

$$J_{NO_2}=8{,}14\cdot10^{-3}(0{,}97674+8{,}37\cdot10^{-4}\cdot$$

$$\cdot(T-273{,}15)++4{,}5173\cdot10^{6}\cdot(T-273{,}15)^2)\,, \quad (10)$$

$$k_1=44{,}05\cdot10^{-3}\exp(-\frac{1370}{T})\,. \quad (11)$$

Nitrogen dioxide decomposes to produce nitric oxide, and latter is oxidized by ozone. As a result of the series of consecutive reactions, one molecule of nitric oxide contributes to the destruction of an average of 10 ozone molecules. NO_2 is more toxic than NO. The scale of NO transformation is 10 km per 1 hour, and NO_2 – 100-200 km per 2 days. To assess the level of air pollution with nitrogen dioxide, taking into account the mutual influence of emissions from industrial enterprises and the highway, it is necessary to solve equations (7) – (9) together. The setting of boundary conditions for solving the transport equations is considered in the works of Marchuk G.I., Samarsky A.A.

As you know, risk is a category of market economy, which is a multi-dimensional concept.

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Risk classification is carried out depending on the main reason for the occurrence of risks: natural, man-made, environmental, commercial. From the point of view of applying the concept of risk in its analysis and management of technological safety, important categories are: individual, potential territorial, social, collective risks.

To describe the risk of chronic intoxication (including the risk of cancer) associated with air pollution, a linear-exponential model is often used [1].

$$R_p = 1 - \exp\left[-0{,}174 \cdot \left(\frac{C}{MPC_{ad} \cdot K_p} \right)^{\beta} \cdot t \right], \quad (12)$$

where R_p is the risk, C is the concentration of a substance that has an impact over time t; β – coefficient taking into account the particular toxic properties of substances; MPC_{ad} – maximum permissible daily average concentration of the chemical substance in the air of populated areas, mg/m^3. This concentration should not have a direct or indirect adverse effect on a person with indefinite inhalation (years). Nitrogen oxides are moderately hazardous substances, they have the 3rd hazard class. Recommended by Alymov V. T., Tarasova N. P. for calculating risk parameter values: $\beta = 1$, $K_p = 4{,}5$.

For the numerical solution of the impurity transfer equation (4) – (6) with respect to the highway and the industrial facility, an implicit difference scheme is used. The essence of this scheme is that the model equations are split into equations of a simpler form. At each step of splitting, the unknown values of the concentrations of nitric oxide NO, nitrogen dioxide NO_2 and ozone O_3 are calculated using the running account method [2, 4, 6]. In each difference cell to calculate the process of chemical transformation, i.e. to solve equations (7) – (9), the Euler method is used. The process of modeling air pollution NO, NO_2, O_3, is reduced to a sequential solution at each time step of equations (4) – (6) and (7) – (9).

As a result of mathematical and numerical modeling, the computer program «Transformation» was developed to conduct computational experiments. Performing calculations using this program is based on the following information: wind speed and direction; the state of the atmosphere; coordinates of pollution sources (industrial facility and motorway); emission intensity of the pollutant; chemical transformation factors; factors included in the model, according to risk assessment.

According to the Dnieper Region Weather Archive, the average direction of the wind directions for the year is the eastern direction (from where it blows) is 15 %.

Findings

The industrial facility PC «Interpipe Nyzhnodniprovskyi Tube Rolling Plant», the NO_x emission intensity of which is Q=14,076 g/s, and the Slobozhansky Avenue highway, which is located in 710 meters from the emission sources (pipes) of the enterprise, are considered. The intensity of the movement of vehicles on the considered section of the road is 300 auto/min with eight straight lines, the relative number of cars per 1 m of the highway is 0,45 auto/m, with NOx emissions per 1 m Q_{avt}=0,012 g/s.

The size of the computational area is 3,5 km by 1,2 km, the wind speed from the east was U =7 m/s. The isolines of NO_2 concentration are shown at the level of z=12 m.

Calculations were made to estimate the level of concentration NO_2 in the atmospheric air, taking into account the impurity only from an industrial enterprise (Fig. 2). In the zone of pollution fall: plant territory – 90 %, Stoletov St. – 80 %, Bazhov St. and Voyennaya St. – 70 %, Izumrudnaya St. and Sapernaya St. – 60 %, Karazin St. and Lugovskaya St. – 50 %, Rostovskaya St. and Tramwaynaya St. – 40 %, Proskurovskaya St. and Lesya Ukrainka St. – 30 %, Svetlaya St. and Radistov St. – 20 %, Yaselnaya St. and Manuylovsky Avenue – 10 %, Karun St. – 5 %.

Fig. 3 shows the zone of pollution, which is formed under the influence of the highway. The following streets in the zone of pollution: Bazhov St. and Voyennaya St. – 80 %, Izumrudnaya St. and Sapernaya St. – 70 %, Karazin St. and Lugovskaya St. – 60 %, Rostovskaya St. and Tramwaynaya St. – 40 %, Proskurovskaya St. and Lesya Ukrainka – 30 %, Svetlaya St. and Radistov St. – 10–20 %, Yaselnaya St. – 5 %.

Fig. 4 shows the zone of pollution, taking into account the mutual influence of emissions from an

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industrial enterprise and the highway. Starting from the first source (plant), a plume of pollution is drawn along the direction of movement of air masses, the percentage of impurities gradually decreases. Having reached the highway, the NO_2 concentration begins to increase again, as the plume of pollution from the second source, taking into account the principle of superposition, is superimposed on the one that is already present in the atmospheric air, the NO_2 concentration of impurities and the pollution zone increases. The concentration of nitrogen dioxide varies according to this dependence: the territory of the plant – 90 %, Stoletov St. – 80 %, Bazhov St. and Voyennaya St. – 80-90 %, Izumrudnaya St. and Sapernaya St. – 70 %, Karazin St. and Lugovskaya St. – 60 %, Rostovskaya St. and Tramwaynaya St. – 50 %, Proskurovskaya St. and Lesya Ukrainka St. – 40 %, Svetlaya St. and Radistov St. – 30 %, Yaselnaya St. and Manuylovsky Avenue – 20 %, Karuna St. – 10 %, Amur-Havanskaya st. – 5 %.

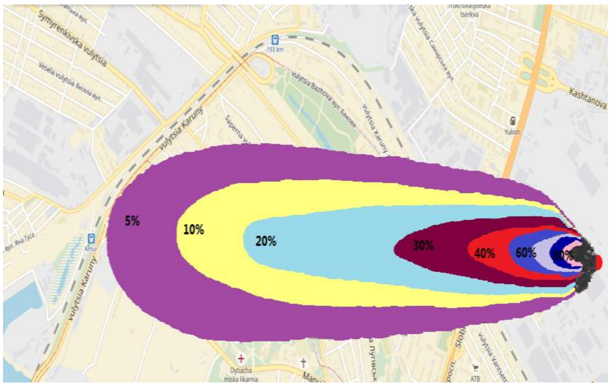

Fig. 2. Nitrogen dioxide pollution zone, one source of pollution – industrial enterprise

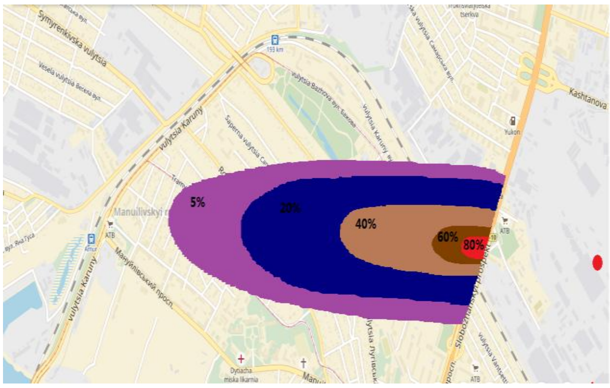

Fig. 3. Nitrogen dioxide pollution zone, one source of pollution – highway

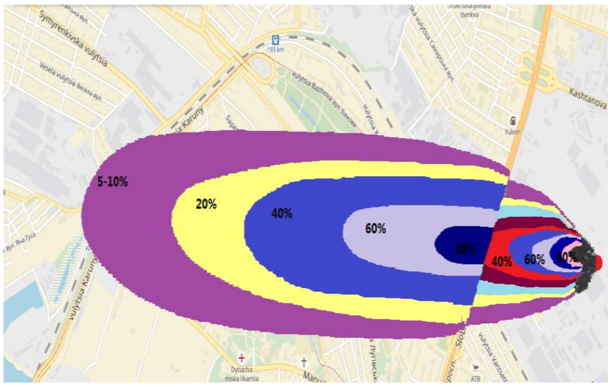

Fig. 4. Nitrogen dioxide pollution zone, two sources of pollution – industrial enterprise and highway.

Fig. 2–4 show the concentration values, which are presented as a percentage of the maximum concentration at this time t=52,5 min: C_{max}=0,0928 mg/m^3 (Fig. 2) – *NOx* emissions are taken into account only from an industrial enterprise C_{max}=0.0359 mg/m^3 (Fig. 3) – *NOx* emissions are taken into account only from the highway, C_{max}=0,1279 mg/m^3 (Fig. 4) – emissions from two pollution sources are taken into account.

The found impurity concentration field allowed us to estimate the change in the risk of chronic intoxication associated with atmospheric air pollution with nitrogen dioxide over 50 years (Fig. 5). The calculation of the risk of chronic diseases was carried out according to model (12), the calculation was considered the concentration of nitrogen dioxide. The risk calculation was performed for points located at a distance of about 30 m from the highway.

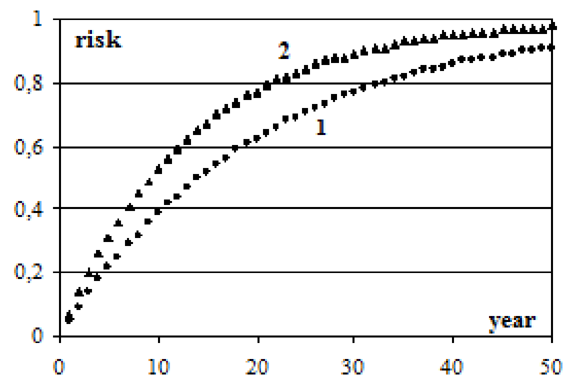

Fig. 5. Changes in the risk of chronic intoxication with nitrogen dioxide:
1 – without taking into account emission highway;
2 – taking into account emissions highway

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Fig. 5 shows that the mutual influence NO_2 emissions from highway and plant lead to the increasing of the chronic diseases risk by 10 %. Thus, it is necessary to develop measures to reduce the risk of disease in this area.

Originality and practical value

For the first time in the paper:

1. The patterns of changing the level of atmospheric air pollution with nitrogen dioxide were established, taking into account one point source of pollution – an industrial enterprise and one linear source of pollution – a highway. A qualitative picture of the field of nitrogen dioxide concentration was obtained taking into account the mutual influence of emissions from an industrial enterprise, the highway and their chemical transformation in the atmosphere.
2. The risk of chronic intoxication has been calculated and its changes have been analyzed taking into account the interaction of emissions from an industrial enterprise and the highway, it has been shown that this leads to an increase in risk of 10 %.
3. A mathematical method was developed for numerical calculation of the pollutant concentration field taking into account the interaction of emissions of various types of pollution sources. Based on it, software has been created that allows to quickly obtain quantitative results necessary in developing a system for monitoring man-made loaded regions of the city.

The obtained patterns of dispersion of impurities allow us to estimate the levels of pollution of the city's territory by emissions from industrial enterprises and highways. Accounting for the mutual influence of emissions and the calculation of risks of intoxication allows solving environmental problems arising in the development of transport strategy in cities and assessing the level of intoxication of workers of the external auction, whose working areas are located in the zone of influence of several pollution sources.

Conclusions

As a result of research, the following results were obtained:

– a mathematical method was developed for the numerical calculation of the concentration of impurities in the atmosphere on the basis of three-dimensional mass transfer equations;

– the method allows to calculate the concentration level separately for a permanently operating point source of pollution or for a linearly distrib uted source of pollution, and taking into account their mutual influence;

– software was developed to carry out computational experiments on the calculation of nitrogen dioxide pollution zones for a single pollution source - an industrial enterprise or a highway, taking into account two sources of admixture;

– the developed method allows to carry out an assessment of the risk of chronic intoxication associated with atmospheric air pollution with nitrogen dioxide for 50 years based on the calculated concentration field.

The development perspective of this direction is the creation of a model that takes into account the leakage of impurities into the buildings.

LIST OF REFERENCE LINKS

1. Алымов, В. Т. Техногенный риск. Анализ и оценка : учеб. пособие для вузов / В. Т. Алымов, Н. П. Тарасова. – Москва : Академкнига, 2004. – 118 с.
2. Марчук, Г. И. Математическое моделирование в проблеме окружающей среды / Г. И. Марчук. – Москва : Наука, 1982. – 320 с.
3. Меньшиков, В. В. Анализ риска при систематическом загрязнении атмосферного воздуха опасными химическими веществами : учеб. пособие / В. В. Меньшиков, А. А. Швыряев, Т. В. Захарова. – Москва : Изд-во МГУ, 2003. – 245 с.
4. Прогноз уровня загрязнения атмосферного воздуха в зоне влияния городских автомагистралей / Н. Н. Беляев, Т. И. Русакова, В. Е. Колесник, А. В. Павличенко // Наук. вісн. Нац. гірн. ун-ту. – 2016. – № 1. – С. 90–98.
5. Стоецкий, В. Ф. Оценка риска при авариях техногенного характера / В. Ф. Стоецкий, В. И. Голинько, Л. В. Дранишников // Наук. вісн. Нац. гірн. ун-ту. – 2014. – № 3. – С. 117–124.
6. Численное моделирование распространения загрязнения в окружающей среде / М. З. Згуровский, В. В. Скопецкий, В. К. Хрущ, Н. Н. Беляев. – Киев : Наук. думка, 1997. – 368 с.

doi: 10.15802/stp2019/159508

7. Berlov, O. V. Atmosphere protection in case of emergency during transportation of dangerous cargo / O. V. Berlov // Наука та прогрес транспорту. – 2016. – № 1 (61). – С. 48–54. doi: 10.15802/stp2016/60953
8. Evaluation of the Danish AirGIS air pollution modeling system against measured concentrations of PM2.5, PM10, and black carbon / U. A. Hvidtfeldt, M. Ketzel, M. Sørensen, O. Hertel, J. Khan, J. Brandt, O. Raaschou-Nielsen // Environmental Epidemiology. – 2018. – Vol. 2. – Iss. 2. doi: 10.1097/EE9.0000000000000014
9. Gómez-Losada, Á. Modelling background air pollution exposure in urban environments: Implications for epidemiological research / Álvaro Gómez-Losada, José Carlos M. Pires, Rafael Pino-Mejías // Environmental Modelling & Software. – 2018. – Vol. 106. – P. 13–21. doi: 10.1016/j.envsoft.2018.02.011
10. Liu, C.-H. Numerical study on the ozone formation inside street canyons using a chemistry box model / Chun-Ho Liu, Dennis Y. C. Leung // Journal of Environmental Sciences. – 2008. – Vol. 20. – Iss. 7. – P. 832–837. doi: 10.1016/s1001-0742(08)62134-8
11. Mărunţălu, O. Mathematical model for air pollutants dispersion emitted by fuel combustion / Oliver Mărunţălu, Gheorghe Lăzăroiu, Dana Andreya Bondrea // U.P.B. Sci. Bull., Series D. – 2015. – Vol. 77. – Iss. 4. – P. 229–236.
12. Merah, A. Modeling and Analysis of NO_x and O_3 in a Street Canyon / A. Merah, A. Noureddine // Der Pharma Chemica. – 2017. – Vol. 9. – Iss. 19. – P. 66–72.
13. Overman, H. T. Simulation model for NOx distribution in a street canyon with air purifying pavement : Master thesis / H. T. Overman ; University Twente. – Enschede, Netherlands, 2009. – 107 p.
14. Source influence on emission pathways and ambient PM2.5 pollution over India (2015–2050) / C. Venkataraman, M. Brauer, K. Tibrewal [et al.] // Atmospheric Chemistry and Physics. – 2018. – Vol. 18. – Iss. 11. – P. 8017–8039. doi: 10.5194/acp-18-8017-2018
15. Zhong, J. Modelling the dispersion and transport of reactive pollutants in a deep urban street canyon: Using large-eddy simulation / J. Zhong, X.-M. Cai, W. J. Bloss // Environmental Pollution. – 2015. – Vol. 200. – P. 42–52. doi: 10.1016/j.envpol.2015.02.009

М. М. БІЛЯЄВ[1*], Т. І. РУСАКОВА[2*]

[1*]Каф. «Гідравліка та водопостачання», Дніпровський національний університет залізничного транспорту імені академіка В. Лазаряна, вул. Лазаряна, 2, Дніпро, Україна, 49010, тел. +38 (056) 273 15 09, ел. пошта water.supply.treatment@gmail.com, ORCID 0000-0002-1531-7882

[2*]Каф. «Аерогідромеханіка та енергомасоперенос», Дніпровський національний університет імені О. Гончара, вул. Козакова, 18, Дніпро, Україна, 49010, тел. +38 (056) 776 82 05, ел. пошта rusakovati1977@gmail.com, ORCID 0000-0001-5526-3578

ВИЯВЛЕННЯ ЗОН ХІМІЧНОГО ЗАБРУДНЕННЯ В МІСТАХ Й ОЦІНКА РИЗИКІВ ХРОНІЧНИХ ЗАХВОРЮВАНЬ

Мета. Наукова робота має за мету створення методології виявлення зон хімічного забруднення на територіях промислових міст і врахування можливості оцінки ризиків хронічних захворювань. **Методика.** Метод чисельного розрахунку концентрації діоксиду азоту в атмосферному повітрі базується на вирішенні тривимірних рівнянь переносу домішки, яка безпосередньо надходить від постійно діючого стаціонарного джерела (промислового підприємства) і лінійно розподіленого джерела (автомагістралі). Методика враховує процес хімічного перетворення домішки і фотолізу в атмосфері. Чисельна модель ґрунтується на розщепленні модельних рівнянь і їх розв'язанні за допомогою неявної різницевої схеми. **Результати.** Створено програмне забезпечення, що дозволяє проводити обчислювальні експерименти з розрахунку зон забруднення атмосферного повітря діоксидом азоту з урахуванням взаємовпливу домішки, що надходить від різних типів джерел забруднення, з урахуванням метеорологічних параметрів. На основі отриманого поля концентрації діоксиду азоту проведена оцінка зміни ризику хронічної інтоксикації, пов'язаного із забрудненням атмосферного повітря діоксидом азоту протягом 50 років. **Наукова новизна.** Уперше встановлено закономірності зміни рівня забруднення атмосферного повітря діоксидом азоту з урахуванням взаємовпливу викидів промислового підприємства й автомагістралі і їх хімічного перетворення в атмосфері. Виконано розрахунок ризику хронічної інтоксикації й проведено аналіз його зміни з урахуванням взаємовпливу викидів промислового підприємства й автомагістралі, показано, що це призводить до зростання ризику на 10 %. **Практична значимість.** Розроблена математична модель і методика чисельного розрахунку, створене на їх

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основі програмне забезпечення дозволяють оперативно отримувати кількісні результати, необхідні під час розробки системи моніторингу техногенно навантажених регіонів міста. Отримані закономірності розсіювання домішки дозволяють оцінити рівні забруднення урбанізованих територій міста викидами промислових підприємств й автомагістралей. Облік взаємовпливу викидів і розрахунок ризиків інтоксикації дозволяє вирішувати екологічні задачі, що виникають під час розробки транспортної стратегії в містах.

Ключові слова: промислове підприємство; автомагістраль; розсіювання домішки; хімічна взаємодія; ризик захворювання

Н. Н. БЕЛЯЕВ[1*], Т. И. РУСАКОВА[2*]

[1*]Каф. «Гидравлика и водоснабжение», Днипровский национальный университет железнодорожного транспорта имени академика В. Лазаряна, ул. Лазаряна, 2, Днипро, Украина, 49010, тел. +38 (056) 273 15 09, эл. почта water.supply.treatment@gmail.com, ORCID 0000-0002-1531-7882

[2*]Каф. «Аэрогидромеханика и энергомассоперенос», Днипровский национальный университет имени О. Гончара, ул. Казакова, 18, Днипро, Украина, 49010, тел. +38 (056) 776 82 05, эл. почта rusakovati1977@gmail.com, ORCID 0000-0001-5526-3578

ВЫЯВЛЕНИЕ ЗОН ХИМИЧЕСКОГО ЗАГРЯЗНЕНИЯ В ГОРОДАХ И ОЦЕНКА РИСКОВ ХРОНИЧЕСКИХ ЗАБОЛЕВАНИЙ

Цель. Научная работа своей целью имеет создание методологии выявления зон химического загрязнения на территориях промышленных городов и учет возможности оценки рисков хронических заболеваний. **Методика.** Метод численного расчета концентрации диоксида азота в атмосферном воздухе основывается на решении трехмерных уравнений переноса примеси, которая непосредственно поступает от постоянно действующего стационарного источника (промышленного предприятия) и линейно распределенного источника (автомагистрали). Методика учитывает процесс химической трансформации примеси и фотолиза в атмосфере. Численная модель основывается на расщеплении модельных уравнений и их решении с помощью неявной разностной схемы. **Результаты.** Создано программное обеспечение, позволяющее проводить вычислительные эксперименты по расчету зон загрязнения атмосферного воздуха диоксидом азота с учетом взаимовлияния примеси, поступающей от различного типа источников загрязнения, с учетом метеорологических параметров. На основе полученного поля концентрации диоксида азота проведена оценка изменения риска хронической интоксикации, связанного с загрязнением атмосферного воздуха диоксидом азота на протяжении 50 лет. **Научная новизна.** Впервые установлены закономерности изменения уровня загрязнения атмосферного воздуха диоксидом азота с учетом взаимовлияния выбросов промышленного предприятия и автомагистрали и их химической трансформации в атмосфере. Выполнен расчет риска хронической интоксикации и проведен анализ его изменения с учетом взаимовлияния выбросов промышленного предприятия и автомагистрали, показано, что это приводит к росту риска на 10 %. **Практическая значимость**. Разработанная математическая модель и методика численного расчета, созданное на их основе программное обеспечение позволяют оперативно получать количественные результаты, необходимые в разработке системы мониторинга техногенно нагруженных регионов города. Полученные закономерности рассеивания примеси позволяют оценить уровни загрязнения урбанизированных территорий города выбросами промышленных предприятий и автомагистралей. Учет взаимовлияния выбросов и расчет рисков интоксикации позволяет решать экологические задачи, возникающие при разработке транспортной стратегии в городах.

Ключевые слова: промышленное предприятие; автомагистраль; рассеивание примеси; химическое взаимодействие; риск заболевания

REFERENCES

1. Alymov, V. T., & Tarasova, N. P. (2004). *Tekhnogennyy risk. Analiz i otsenka: uchebebnoe posobie dlya vuzov*. Moscow: Akademkniga. (in Russian)
2. Marchuk, G. I. (1982). *Matematicheskoye modelirovaniye v probleme okruzhayushchey sredy*. Moscow: Nauka. (in Russian)
3. Menshikov, V. V., Shvyryaev, A. A., & Zakharova, T. V. (2003). *Analiz riska pri sistematicheskom zagryaznenii atmosfernogo vozdukha opasnymi khimicheskimi veshchestvami: uchebnoe posobie*. Moscow: Izdatelstvo MGU. (in Russian)

doi: 10.15802/stp2019/159508

4. Biliaiev, N. N., Rusakova, T. I., Kolesnik, V. Ye., & Pavlichenko, A. V. (2016). The predicted level of atmospheric air pollution in the city area affected by highway. *Scientific Bulletin of National Mining University, 1,* 90-98. (in Russian)
5. Stoetsky, V. F., Golinko, V. I., & Dranishnikov, L. V. (2014). Risk assessment in man-caused accidents. *Scientific Bulletin of National Mining University, 3,* 117-124. (in Russian)
6. Zgurovskiy, M. Z., Skopetskiy, V. V., Khrushch, V. K., & Belyaev, N. N. (1997). *Chislennoe modelirovanie rasprostraneniya zagryazneniya v okruzhayushchey srede.* Kyiv: Naukova Dumka. (in Russian)
7. Berlov, O. V. (2016). Atmosphere protection in case of emergency during transportation of dangerous cargo. *Science and Transport Progress, 1(61),* 48-54. doi: 10.15802/stp2016/60953 (in English)
8. Hvidtfeldt, U. A., Ketzel, M., Sørensen, M., Hertel, O., Khan, J., Brandt, J., & Raaschou-Nielsen, O. (2018). Evaluation of the Danish AirGIS air pollution modeling system against measured concentrations of PM2.5, PM10, and black carbon. *Environmental Epidemiology, 2(2)*. doi: 10.1097/ee9.0000000000000014 (in English)
9. Gómez-Losada, Á., Pires, J. C. M., & Pino-Mejías, R. (2018). Modelling background air pollution exposure in urban environments: Implications for epidemiological research. *Environmental Modelling & Software, 106,* 13-21. doi: 10.1016/j.envsoft.2018.02.011 (in English)
10. Liu, C.-H., & Leung, D. Y. C. (2008). Numerical study on the ozone formation inside street canyons using a chemistry box model. *Journal of Environmental Sciences, 20(7),* 832-837. doi: 10.1016/s1001-0742(08)62134-8 (in English)
11. Mărunţălu, O., Lăzăroiu, G., & Bondrea, D. A. (2015). Mathematical model for air pollutants dispersion emitted by fuel combustion. *U.P.B. Sci. Bull., Series D, 77(4),* 229-236. (in English)
12. Merah, A., & Noureddine, A. (2017). Modeling and Analysis of NO_x and O_3 in a Street Canyon. *Der Pharma Chemica, 9(19),* 66-72. (in English)
13. Overman, H. T. (2009). *Simulation model for NO_x distribution in a street canyon with air purifying pavement.* (Master thesis). University Twente, Enschede, Netherlands. (in English)
14. Venkataraman, C., Brauer, M., Tibrewal, K., Sadavarte, P., Ma, Q., Cohen, A., … Wang, S. (2018). Source influence on emission pathways and ambient PM2.5 pollution over India (2015–2050). *Atmospheric Chemistry and Physics, 18(11),* 8017-8039. doi: 10.5194/acp-18-8017-2018 (in English)
15. Zhong, J., Cai, X.-M., & Bloss, W. J. (2015). Modelling the dispersion and transport of reactive pollutants in a deep urban street canyon: Using large-eddy simulation. *Environmental Pollution, 200,* 42-52. doi: 10.1016/j.envpol.2015.02.009 (in English)

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