Науковий вісник НЛТУ України
Scientific Bulletin of UNFU
https://doi.org/10.36930/40340703
Article received 23.10.2024
Article accepted 21.11.2024
UDC 504.4(477.86)
Correspondence author: N. V. Latsyk nataliia.v.latsyk@lpnu.ua

ISSN 1994-7836 (print)
ISSN 2519-2477 (online)

***N. V. Latsyk, I. M. Petrushka***
*Lviv Polytechnic National University, Lviv, Ukraine*

# MODELING OF THE PROCESS OF SPREADING FINE DUST IN THE ATMOSPHERE OF RESIDENTIAL AREAS

The features of modeling the dispersion process of fine dust in the atmosphere of residential areas were examined, which not only enhanced understanding of cement dust dispersion processes but also allowed for the development of practical recommendations to mitigate its negative impact on the environment and public health. It is well known that cement production is a primary source of air pollutants, particularly cement dust, which degrades atmospheric quality and poses a serious health risk to nearby populations. The research employed a combination of mathematical modeling and data analysis to predict the dispersion of cement dust in residential areas adjacent to industrial facilities. The model simulated the behavior of particulate matter in the atmosphere, accounting for variables such as wind direction, emission rates, and particle size. Consequently, the study provided an accurate forecast of dust concentrations at varying distances from the emission source, offering valuable insights into the scope of the pollution. Moreover, the analysis revealed that cement dust disperses over wide areas, leading to elevated levels of particulate matter in residential zones, which can significantly affect human health, especially respiratory conditions. In addition to modeling, the study assessed the efficiency of current dust collection systems in cement production plants. It was found that improvements in dust collection technologies could result in a 10-15 % reduction in dust emissions. As a result, the study advocates for the modernization of filtration and capture equipment as a practical solution for mitigating the environmental footprint of cement production. The benefits of this research extend beyond immediate air quality improvements, as the reduction in emissions could lead to enhanced public health outcomes and a decrease in long-term environmental damage. The findings underscore the importance of continuous air quality monitoring and regulatory compliance to control industrial pollution. The study's conclusions suggest that further research is needed to refine the dust dispersion model by incorporating additional environmental factors such as humidity, temperature, and urban landscape features. Future studies could also explore the long-term effectiveness of improved dust collection technologies in diverse climatic and geographic conditions.

**Keywords:** sustainable development; aerosol systems; air quality monitoring; mathematical modeling.

## Introduction / Вступ

In global scientific literature, the impact of cement production emissions on atmospheric air quality has been widely studied. Numerous studies have focused on the dispersion of dust particles and their effects on the health of populations living near cement plants. The efficiency of dust collection systems, aerosol processes, and the mathematical modeling of pollutant dispersion in the atmosphere using modern models such as AERMOD, CALPUFF, and others have also been examined [7, 25]. However, insufficient attention has been paid to modeling the migration of fine particulate matter in specific residential areas and complex topographical conditions. The issue of improving mathematical models for accurately predicting cement dust dispersion, taking into account local meteorological and geographical factors, remains unresolved. To optimize mathematical models of cement dust dispersion, it is necessary to adapt them to local meteorological and geographical conditions and calibrate based on monitoring data. The application of numerical methods and regular model updates will enhance forecast accuracy, enabling effective decision-making to reduce environmental impact [8].

*Object of research* – distribution of fine dust in the atmosphere of residential areas adjacent to the PJSC Ivano-Frankivskcement cement plant.

*Subject of research* – modeling of the process of the spread of fine dust in the atmosphere of residential areas, which takes into account emission sources, meteorological conditions and geographical features, and also makes it possible to forecast pollution and assess their impact on the environment.

**Інформація про авторів:**
**Лацик Наталія Володимирівна**, аспірант, кафедра екологічної безпеки та природоохоронної діяльності.
**Email:** nataliia.v.latsyk@lpnu.ua; https://orcid.org/0000-0001-7539-2799
**Петрушка Ігор Михайлович**, д-р техн. наук, професор, завідувач кафедри екологічної безпеки та природоохоронної діяльності.
**Email:** ihor.m.petrushka@lpnu.ua; https://orcid.org/0000-0003-3344-4196

**Цитування за ДСТУ:** Лацик Н. В., Петрушка І. М. Моделювання процесу поширення дрібнодисперсного пилу в атмосфері житлових районів. Науковий вісник НЛТУ України. 2024, т. 34, № 7. С. 23–29.
**Citation APA:** Latsyk, N. V., & Petrushka, I. M. (2024). Modeling of the process of spreading fine dust in the atmosphere of residential areas. *Scientific Bulletin of UNFU*, 34(7), 23–29. https://doi.org/10.36930/40340703

*The* purpose *of the* research – to develop a mathematical model that takes into account key parameters such as emission sources, meteorological conditions, and geographical features to accurately predict pollution levels and assess their impact on the environment in residential areas.

To achieve this *purpose*, the following main *research objectives are identified*:

1. Analysis of emission sources, which will enable the identification of key parameters of cement dust emissions, such as intensity and chemical composition.
2. Development of a mathematical model, which will allow for accurate simulation of dust dispersion and deposition processes based on the collected data.
3. Study of meteorological conditions, which will provide the opportunity to investigate local weather factors that influence dust dispersion and deposition, such as wind direction, temperature, and humidity.
4. Model validation, which will enable the verification of its accuracy and reliability based on real-world observations from nearby areas.
5. Investigation of geographical features, which will ensure an understanding of the impact of topography and terrain on the accumulation of cement dust in residential areas.
6. Assessment of environmental and health impacts, which will ensure an understanding of the consequences of pollution for the ecosystem and the health of residents in adjacent areas.

These objectives will help develop an effective strategy for managing air pollution caused by cement production.

**The analysis of recent research and publications**. An analysis of recent studies and publications indicates that the issue of atmospheric air pollution by cement dust is one of the key challenges in the context of technogenic environmental load. Numerous scientific works are devoted to studying the impact of emissions from cement plants on the ecological state of areas adjacent to industrial enterprises, as well as their negative effects on human health. These studies thoroughly examine the dispersion of cement dust and its impact on air quality, highlighting the urgent need for control and minimization of emissions. Additionally, considerable attention is paid to analyzing the efficiency of dust collection systems, which play a crucial role in reducing dust concentration in the atmosphere [11, 15].

Research [2] provides a fundamental understanding of the technical aspects of mathematical air quality modeling, discussing various approaches – box, Gaussian, Eulerian, Lagrangian, and particle models – and drawing conclusions about the future of this field. Specifically, studies [19] focus on the mathematical modeling of dust dispersion processes in the air using modern models such as AERMOD and CALPUFF. These models allow for accurate prediction of pollution levels by considering factors like meteorological conditions, terrain relief, and emission source parameters. However, as noted in works [16, 23], existing models often do not account for the specific local conditions in residential areas, which limits their applicability for pollution forecasting in such regions.

Thus, the necessity for further improvement of atmospheric dust dispersion models, taking into account specific local meteorological and geographical conditions, becomes evident. This will not only enhance the accuracy of forecasts but also enable the development of more effective measures to reduce technogenic load on ecosystems and public health.

**Materials and methods of research.** To investigate the dispersion of finely dispersed cement dust in the atmosphere of residential areas, a comprehensive approach was applied, involving the collection of empirical data and mathematical modeling. Primary data regarding emission sources and their characteristics were obtained from production reports of cement enterprises and environmental agencies. This allowed for the consideration of emission parameters such as source height, emission speed and volume, and particle size distribution [6].

Mathematical modeling of cement dust dispersion was conducted using the AERMOD software package, which is recommended by the United States Environmental Protection Agency (EPA) and is widely used for air quality assessment [14]. This model accounts for complex meteorological and topographical conditions, as well as the physicochemical properties of dust.

The obtained data were analyzed using statistical methods to identify patterns in the dispersion of cement dust and the influence of meteorological factors on pollution levels.

## Research result and their discussion / Результати дослідження та їх обговорення

Research by leading scientists suggests that dust pollution of the lower atmosphere poses a significant threat to the environment and human health. Solid dust particles, depending on their characteristics, can have a variety of negative effects [5, 17, 20]. Fine dust has the greatest fibrogenic activity, its particles penetrate the deepest and are retained by the alveoli of the lungs, which causes a number of specific diseases, which necessitates measures to reduce the flow of pollutants into the air of settlements and predict the distribution of dust particles in atmospheric air [1].

To develop a mathematical model of the fine dust propagation process, we use the differential diffusion transport equation, this equation describes how the concentration of dust particles changes with time and three-dimensional space:

$$\frac{\partial C}{\partial \tau} + u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} + w\frac{\partial C}{\partial z} + \sigma^* C = \frac{\partial}{\partial z} y \frac{\partial C}{\partial z} + \mu^* \nabla^2 C + k\,, \quad (1)$$

where: $u$, $v$, $w$ are wind speed parameters along the Cartesian coordinate system axis, m/s; $\mu^*$– horizontal diffusion coefficient in the plane ($x$, 0, $y$), $m^2/s$; $y$ – vertical diffusion coefficient in $z$ – direction, $m^2/s$.

The product of the Laplace operator for concentration is calculated from the following relationship:

$$\nabla^2 C = \frac{\partial^2 C}{\partial x^2} + \frac{\partial^2 C}{\partial y^2}\,, \quad (2)$$

where: $k$ – coordinate and time dependent source parameter, $k = f(x, y, z, t)$; $\sigma^*$ – value associated with substance transformation, $s – 1$.

The authors [1, 3, 10] present that in order to solve this one-dimensional problem of modeling the propagation of fine dust in the atmosphere, equation 1 is considered in a simplified form, while taking into account that the transfer of solid particles in the atmosphere occurs under the condition $-\infty < x < \infty$, that is, in an infinite medium.

Using the data of meteorological conditions in relation to the characteristics of the wind load, as well as taking into account the stationary process of loading on the atmosphere, equation (1) takes the form:

$$u\frac{dC}{dx} + \sigma^* C = \mu^* \frac{d^2 C}{dx^2} + Q\delta(x - x_0)\,, \quad (3)$$

where: $Q$ – power of the source emitting dust into the atmosphere, kg/s; $\delta(x - x_0)$ – dirac delta function, which takes into account the integral content of dust particles that diffuse in the volume of air in height, as well as the number of particles settling on the surface of the earth, $1/m^3$.

When solving this equation, the following boundary conditions are taken into account that the limit of dust dispersion is a stationary source is the size of the sanitary protection zone (SPZ) of the enterprise; the source is in the center of coordinates; source emission power is a constant value [10, 12, 21].

The solution of equation (3) to obtain numerical data is possible using finite difference dependencies.

To do this, it is necessary to discretize the space of distribution of contamination of solid dust particles, taking into account the distance from the source to the boundary of the SPZ of the enterprise at certain intervals.

Space sampling is an important step in the numerical solution of differential equations, such as the diffusion transfer equation. One popular method for this is the finite difference method. This method consists in replacing differential operators with difference operators, which allows you to turn a differential equation into a system of algebraic equations. Consider the space sampling for the one-dimensional diffusion equation:

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2}, \qquad (4)$$

Suppose that we sample space in increments of $\Delta x$ and time in increments of $\Delta t$. Denote the concentration at point $x_i = i{\cdot}\Delta x$ and at time $t_n = n{\cdot}\Delta t$ as $C_i^n$.

Then we can take advantage of spatial and temporal discrediting:

1) Differential equation (3) under the condition – $x = x_i$, $i = \overline{1, n-1}$ can be replaced by a linear equation:

$$\mu_i \frac{C_{i+2} - 2C_{i+1} + C_i}{h^2} + u_i \frac{C_{i+1} - C_{i-1}}{2h} + \sigma_i C_i = Q\delta(x - x_0). \qquad (5)$$

2) Transforming equation (5) with respect to $C_i - 1$, $u_i$ and $C_i + 1$, we obtain a relationship for calculating the concentration of fine dust:

$$\left(\frac{\mu_i}{h^2} - \frac{u_i}{4h}\right)C_{i-1} + \left(\frac{-4\mu_i}{h^2} + \frac{\delta}{1-h}\right)C_i + \left(\frac{\mu_i}{h^2} - \frac{u_i}{4h}\right)C_{i+1} = Q\delta(x - x_0). \qquad (6)$$

To be able to predict the concentration of fine dust at a certain distance from the source of dispersion, it is necessary to take into account the wind speed and power of the source, and it is necessary to use the dispersion equation of dust inclusions in the atmosphere. Using this equation, you can determine the distribution of dust concentrations depending on the height and distance and the source of the emission, taking into account the wind speed.

Most domestic and foreign scientists use the Gauss scattering equation [18, 22] to simulate the scattering of pollutants in the atmospheric environment. This equation takes into account parameters such as wind speed, emission source power, source height, and atmospheric turbulence.

For the selected object of research, the calculation of the degree of distribution of fine particles of cement production took into account the following data: the power of the emission source $8.4{\cdot}10^{-3}$ kg/s; the average wind speed is 1.5 m/s, the distance from the source is 1000 m, the horizontal diffusion coefficient is taken accordingly [1] as for an aerosol – 1.5 $m^2$/s. The simulation results are shown in Figure 1, indicate that the profile of change in dust concentrations from the emission source is uniform.

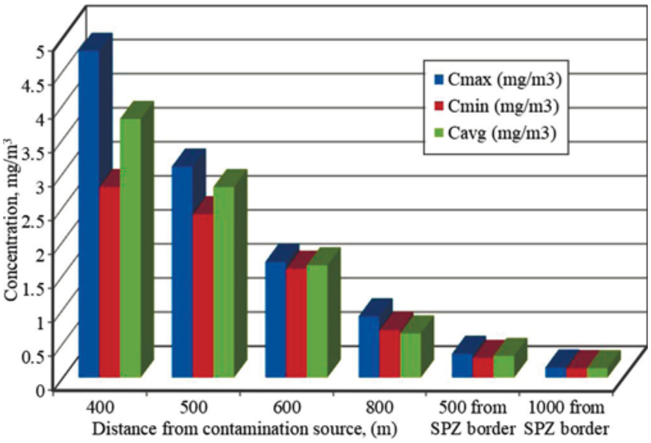


**Fig. 1.** Fine dust concentration distribution from emission source / Розподіл концентрацій дрібнодисперсного пилу від джерела викиду

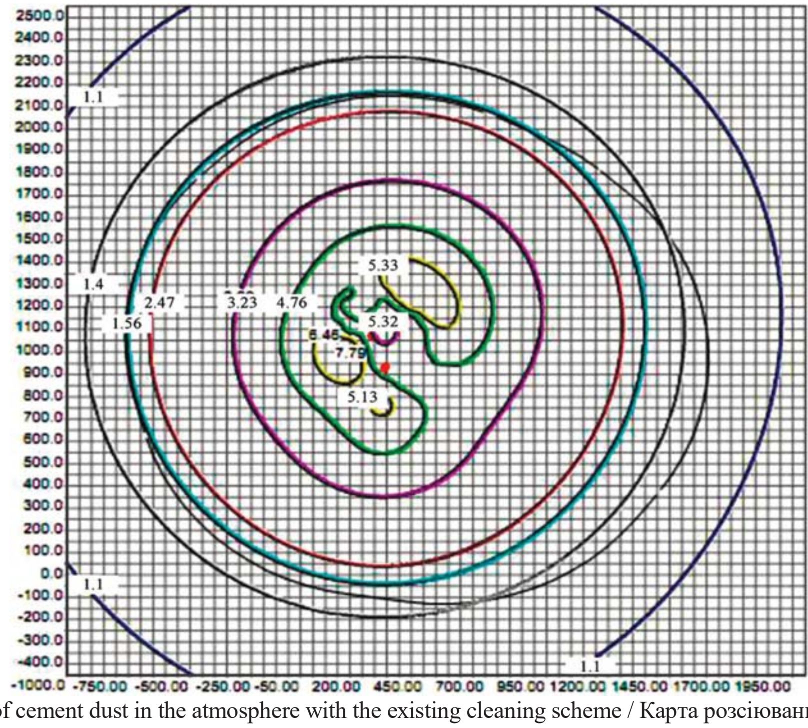


**Fig. 2.** Map of dispersion of cement dust in the atmosphere with the existing cleaning scheme / Карта розсіювання цементного пилу в атмосфері 12 за наявної схеми очищення

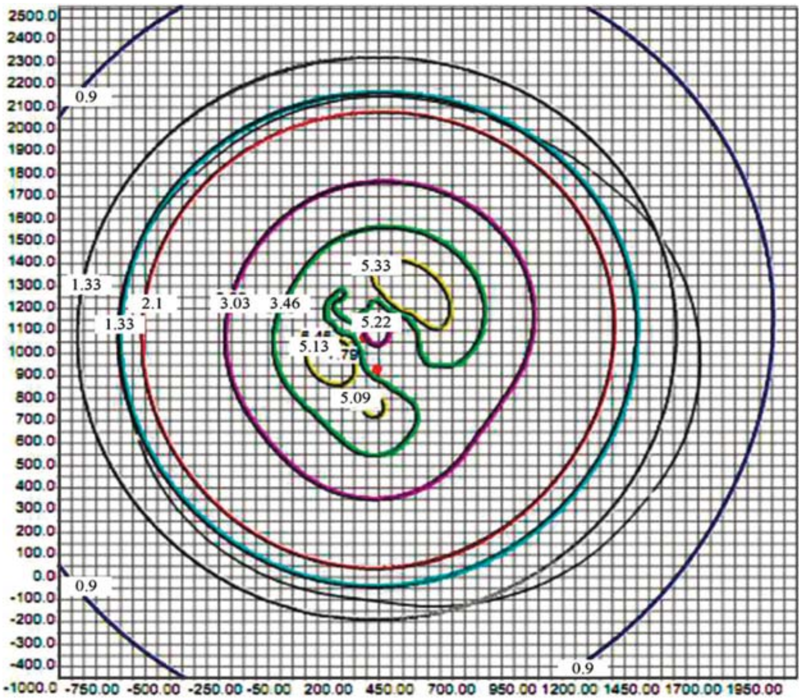


**Fig. 3.** Map of dispersion of cement dust in the atmosphere under the proposed scheme of air cleaning from cement dust / Карта розсіювання цементного пилу в атмосфері за пропонованої схеми очищення повітря від цементного пилу

Calculations and model (Figure 1) together characterize the circular wind direction. The greatest amount of impurities falls at some distance from the emission source due to the transfer of air masses. This is due to the high inertia of fine dust, the particles of which are picked up and transported with the flow of wind. For a visual expression of the results of the obtained mathematical model, we built scattering maps of pollutants depending on the distance from the source which are shown in Figures 2 and 3.

Experimental data on the degree of concentration of pollutants in the dispersion of cement dust according to the existing technological process are 10-15 % higher according to the technological scheme proposed by us.

Based on the results of verification of the adequacy of the mathematical model of fine dust dispersion and experimental data, it was established that the deviation of the calculated values of the mathematical model from the experimental results does not exceed 20 % over the entire studied range of distances (Figure 4).

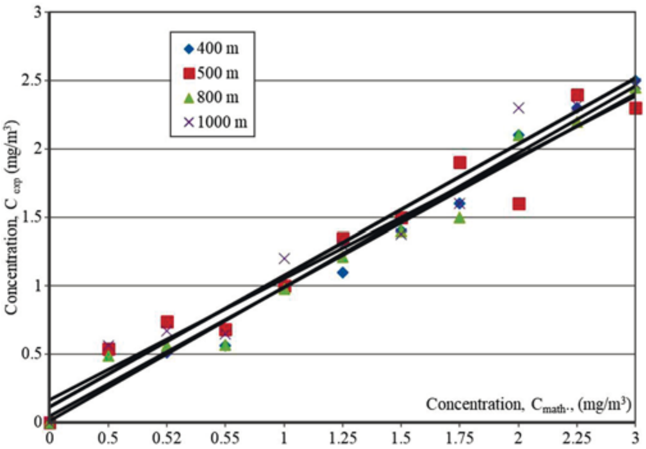


**Fig. 4.** Comparison of calculation results on dependence (6) and experimental data on concentration of cement dust in atmosphere / Порівняння результатів розрахунку за залежністю (6) та експериментальними даними концентрації цементного пилу в атмосфері

The Pearson correlation coefficient that characterizes a measure of covariance, one whose result is always within −1 and 1. It is a statistical measure that estimates the strength and path of the linear coupling of an equation with two variables. In relation to the obtained experimental and trend lines, the Pearson correlation coefficient ($R_2$) is in the range of 0.85-0.95.

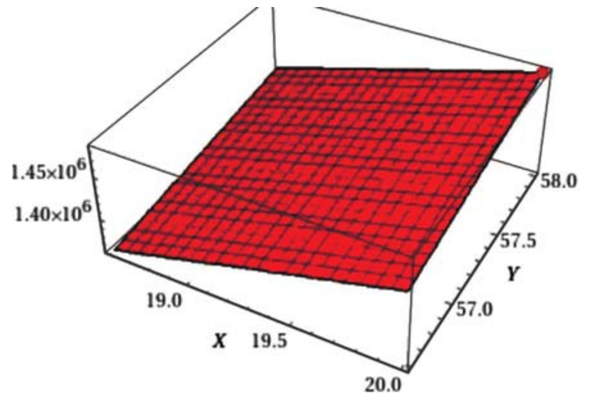


**Fig. 5.** 3D graph of the distribution of polluted air in real conditions, taking into account the boundary conditions and the introduction of cleaning equipment according to the developed utility model patent / 3D-графік розподілу забрудненого повітря в реальних умовах з урахуванням граничних умов та впровадження очисного обладнання відповідно до розробленої патентної моделі

The calculation of the proposed model, taking into account the boundary conditions, allows us to compare the 3D graphic distribution of cement dust in real conditions, depending on the distance from the source of pollution, provided that the proposed device is implemented to effectively clean the air from cement dust [18]. The solutions of criterial equations and the construction of graphical dependencies are obtained using the Wolfram Alpha program in Figure 5 in the following sequence.

Interpreting as:

$$maximize\ Y \cdot 158{,}24 \cdot 17{,}2 \cdot X \cdot \frac{X^{0{,}754} \cdot Y^{0{,}15}}{2{,}24 \cdot X^{0{,}94}} \to \max \qquad (7)$$

in $$12 \le X \le 20;\ 23 \le Y \le 58\ . \tag{8}$$

Global maximum:

$$\max\left\{ Y158{,}24 \cdot 17{,}2 \cdot X \frac{X^{0,754} Y^{0,15}}{2{,}24 X^{0,94}} \middle| 12 \le X \le 20 \wedge 23 \le Y \le 58 \right\} = \\ = \frac{6737932912839621 \cdot 2^{389/500} 5^{407/500} 29^{3/20}}{47804853377} at(X,Y) = (20{,}58). \tag{9}$$

Therefore, the proposed mathematical model of dispersion of solid particles with sufficient accuracy describes the process of dust propagation in atmospheric air.

**Discussion of research results.** An analysis of recent scientific studies underscores the importance of mathematical modeling for predicting the dispersion of pollutants in the atmosphere, particularly cement dust. Study [4] demonstrates the use of the AERMOD model for simulating the dispersion of pollutants from cement plants in urban conditions. The results show that dust concentration significantly depends on terrain relief, meteorological conditions, and characteristics of emission sources, confirming the necessity of applying models that account for local features for accurate prediction of the environmental impact of industrial emissions.

In study [24], mathematical modeling of industrial emission dispersion, including aerosols, is presented, with calculations of concentration profiles at various distances from the source. The use of differential equations allows for a detailed description of the spread of fine particles in the atmosphere and predicts their concentrations with high accuracy. This contributes to a better understanding of the dynamics of pollutant dispersion and the assessment of potential impacts on human health and ecosystems.

Study [13] emphasizes air quality as a key indicator of sustainable urban development. Air quality directly affects public health and the environmental sustainability of a city. The use of mathematical models to predict pollution events aids in urban planning and the development of sustainable development strategies aimed at reducing emissions and improving the quality of life.

Article [9] explores the integration of air quality models with environmental systems for monitoring and predicting pollutant levels in the atmosphere. Combining models with real data increases the accuracy of forecasts and contributes to achieving sustainable development goals through optimized environmental management. This underscores the role of mathematical modeling in supporting decision-making to improve air quality and protect public health.

The overall analysis of these studies indicates the critical role of mathematical modeling in modern environmental management. Improving pollutant dispersion models by considering specific local meteorological and geographical conditions is necessary to enhance forecast accuracy. This enables the development of more effective measures to reduce technogenic pressure on ecosystems and improve the population's quality of life. The scientific novelty and practical significance of these studies lie in the potential to create advanced air quality monitoring systems and support environmental policies aimed at protecting human health and the environment.

So, based on the results of the work performed, it is possible to formulate the following scientific novelty and practical significance of the research results.

*Scientific novelty of the obtained research results* – for the first time, a mathematical model for the dispersion of finely dispersed cement dust in the atmosphere of residential areas was developed, which takes into account the key parameters of emission sources, meteorological conditions, and geographical features of the area; the methods for modeling dust deposition processes were improved based on calculations of the spatial distribution of particulate matter concentrations, allowing for accurate forecasting of the impact on air quality under real production conditions; the methodology for assessing environmental risks from industrial emissions on the environment and public health was further developed.

*Practical significance of the research results* – the developed mathematical model of fine cement dust dispersion can be applied for predicting particulate concentrations in the atmosphere of residential areas adjacent to industrial facilities, which will allow the development of effective measures to minimize air pollution and its impact on public health, as well as implement improved dust collection systems at cement plants to reduce emissions by 10-15 %, contributing to the improvement of the environmental situation and the reduction of the technogenic burden on the environment.

## Conclusion / Висновки

A mathematical model has been developed that takes into account emission sources, meteorological conditions and geographical features, and also makes it possible to accurately forecast pollution levels and assess their impact on the environment in residential areas. Based on the results of the research the following main conclusions can be drawn.

1. During the research, a mathematical model for the dispersion of finely dispersed cement dust in the atmosphere was developed. For the first time, factors such as emission source parameters, meteorological conditions, and geographical features of the locality were taken into account. This allowed for accurate predictions of dust concentrations at various distances from the pollution source and provided an objective assessment of the pollution scale.
2. The analysis showed that cement dust is capable of spreading over significant distances from the emission source, leading to elevated concentrations of particulate matter in residential areas. This can negatively affect air quality and public health, particularly respiratory diseases. The findings underscore the necessity of monitoring and controlling dust levels in areas adjacent to industrial zones.
3. The AERMOD software package, widely accepted for air quality forecasting, was used for the modeling. The model demonstrated its effectiveness, as the simulation results were consistent with experimental data, confirming its accuracy and reliability. This provides the possibility for the broad application of this approach to other industrial facilities.
4. An important practical conclusion of the research was that the modernization of existing dust collection systems at cement plants could lead to a 10-15 % reduction in cement dust emissions. This will significantly reduce the technogenic load on the environment and enhance the level of environmental safety in areas surrounding cement plants.
5. The results emphasize the importance of implementing modern air purification technologies at cement plants. It was established that such measures can effectively reduce dust concentrations in the atmosphere. The research also highlights the importance of continuous air quality monitoring to promptly detect any pollution limit exceedances.
6. The proposed mathematical model can be used for the planning and implementation of environmental protection measures. This will allow for better forecasting of pollution levels under real production conditions and the development of more effective strategies to reduce the negative im-

pact of cement dust on the environment and public health. The model can also be applied to other types of industrial emissions, making it a universal tool in environmental management.

Thus, the results of the research have important theoretical and practical significance, as they not only enhance the understanding of cement dust dispersion processes but also provide practical recommendations for mitigating its negative impact on the environment and public health.

## References


1. Adamenko, M. I., Katsman, M. D., & Biletska, Y. S. (2018). Analysis of existing mathematical models and computer programs for predicting the dispersion of pollutants in the atmosphere. *Bulletin of V. N. Karazin Kharkiv National University. Series: Systems, Operations and Informatics*, 152, 157–162. https://doi.org/10.30748/soi.2018.152.2221
2. Agrawal, M., Tiwari, A. N., & Saxena, P. K. (2021). Sustainable practices in cement industry. Proceedings of the Institution of Civil Engineers – Engineering Sustainability, *174*(6), 291–305. https://doi.org/10.1680/jensu.20.00004
3. Alentum Software, Inc. (2009). *Advanced Grapher 2.2* [Computer software]. URL: http://www.alentum.com/agrapher/
4. Ali, M. H., & Shafie, S. M. (2018). Modeling of cement factory air pollution dispersion by AERMOD. *Journal of Environmental and Public Health, 2018*. URL: https://www.researchgate.net/publication/323129169_Modeling_of_Cement_Factory_Air_Pollution_Dispersion_by_AERMOD
5. Andrew, R. M. (2018). Global $CO_2$ emissions from cement production. *Earth System Science Data, 10*(1), 195–217. https://doi.org/10.5194/essd-10-195-2018
6. Chen, T., & Sun, H. (2018). Emission factors and control technologies of particulate matter in the cement industry. *Journal of Cleaner Production, 185*, 1060–1068. https://doi.org/10.1016/j.jclepro.2018.02.295
7. Damtoft, J. S., Lukasik, J., Herfort, D., Sorrentino, D., & Gartner, E. M. (2008). Sustainable development and climate change initiatives. *Cement and Concrete Research, 38*(2), 115–127. https://doi.org/10.1016/j.cemconres.2007.09.008
8. El-Sayed, M. A., Faheim, A. A., Salman, A. A., & Saleh, H. M. (2021). Introductory chapter: Cement industry. In *Cement industry – Optimization, Characterization and Sustainable Application*. https://doi.org/10.5772/intechopen.95053
9. Garcia, M., & Torres, E. (2019). Air quality monitoring and modelling using ground monitoring and mathematical models. In *Advances in Environmental Research,* 21, 112–130. Springer. https://doi.org/10.1007/978-3-031-45300-7_9
10. Horyachev, H., & Havryliuk, M. (2010). Modeling the dispersion of pollutants in the atmospheric air using GIS technologies based on the OND-86 methodology. *Scientific Works of Vinnytsia National Technical University*, 3, 1–5. [In Ukrainian]. URL: https://trudy.vntu.edu.ua/index.php/trudy/article/view/157
11. Kovalenko, L. O. (2016). Analysis of air pollution monitoring. *Problems of Urban Environment Development*, 2, 168–177. [In Ukrainian]. URL: http://nbuv.gov.ua/UJRN/Prms_2016_2_21
12. Kozii, I. S., & Hurets, L. L. (2012). Research on dust emissions in titanium dioxide production. *Bulletin of Sumy State University. Series: Technical Sciences*, 4, 180–185. [In Ukrainian]. URL: http://nbuv.gov.ua/UJRN/VSU_tekh_2012_4_25
13. Lee, S., & Chen, Y. (2020). Air quality and urban sustainable development: The application of mathematical models. *International Journal of Environmental Science and Technology, 17*(12), 3425–3437. https://doi.org/10.1007/s13762-020-02896-6
14. Li, L., Wang, H., & Guo, X. (2019). Influence of meteorological conditions on PM2.5 and PM10 concentrations during high pollution episodes in a megacity in China. *Environmental Science and Pollution Research, 26*(3), 2436–2448. https://doi.org/10.1007/s11356-018-3774-5
15. Lviv Polytechnic National University. (2022). Proceedings of the International Scientific and Technical Congress on Ecology, Environmental Protection, and Balanced Nature Management 2022. [In Ukrainian]. URL: https://science.lpnu.ua/sites/default/files/attachments/2022/jan/26205/zbirnykmaterialivekokongres2022.pdf
16. McMullan, E. G. (2011). Air quality modelling: A technical review of mathematical approaches. Meteorological Applications, *18*(3), 1–7. https://doi.org/10.1002/met.285
17. Mokin, V. B., & Varchuk, I. V. (2013). Modeling the dispersion of pollutants in city air using geoinformation technologies. *Bulletin of Vinnytsia Polytechnic Institute*, 5, 13–18. [In Ukrainian].
18. Petrushka, I. M., Latsyk, N. V., & Kulyk, M. P. (2024). Dust Collection System: Patent 155139 Ukraine: B01D 29/00, B01D 46/02. No u 2022 02724; applied on 24.08.2023; published on 24.01.2024; Bulletin No. 4.
19. Petryk, M. R., Khimich, O. M., & Boyko, I. V. (2020). Highly productive methods of modeling and identification of complex processes and objects in multicomponent inhomogeneous environments: monography. Kyiv: *National Academy of Sciences of Ukraine: Institute of Cybernetics. V. Glushkova*, 204. [In Ukrainian]. URL: http://elartu.tntu.edu.ua/handle/lib/34451
20. Pliatsuk, L. D., & Hurets, L. L. (2016). Improving air quality based on environmental safety management at industrial enterprises. *Sciences of Europe, 1*(3), 62–66. [In Ukrainian].
21. Polutrenko, M. S., & Paranyak, N. M. (2015). Improving the efficiency of dust collection systems using developed modified equipment. *Scientific Notes*, 52, 54–59. [In Ukrainian]. URL: http://nbuv.gov.ua/UJRN/Nn_2015_52_12
22. Serebryanskyi, D. O., Plashykhin, S. V., Beznosyk, Y. O., & Nabok, O. M. (2014). Mathematical modeling of dust-laden gas flow purification in a cyclone dust collector. *Eastern-European Journal of Enterprise Technologies, 2*(68), 11–16. [In Ukrainian]. https://doi.org/10.15587/1729-4061.2014.23351
23. Singh, A. K., & Kumar, N. (2024). Impact of environmental pollution on public health: Challenges and future directions. *Discover Sustainability*. https://doi.org/10.1007/s41810-024-00241-9
24. Smith, J., & Brown, P. (2021). Industrial emissions effect into atmospheric air quality: Mathematical modeling. *Reviews on Environmental Health, 36*(1), 45–60. https://doi.org/10.1515/reveh-2022-0005
25. World Health Organization. (2018). Ambient (outdoor) air quality and health. URL: https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health



***Н. В. Лацик, І. М. Петрушка***

*Національний університет "Львівська політехніка", м. Львів, Україна*


## МОДЕЛЮВАННЯ ПРОЦЕСУ ПОШИРЕННЯ ДРІБНОДИСПЕРСНОГО ПИЛУ В АТМОСФЕРІ ЖИТЛОВИХ РАЙОНІВ


Розглянуто особливості моделювання процесу поширення дрібнодисперсного пилу в атмосфері житлових районів, що не тільки покращило розуміння процесів диспергування цементного пилу, а й дало змогу розробити практичні рекомендації з пом'якшення його негативного впливу на довкілля та здоров'я населення. Встановлено, що сталий розвиток країни передбачає потребу забезпечення балансу між економічним зростанням, соціальним добробутом та екологічною безпекою. Встановлено, що одним із ключових чинників впливу на екологічну безпеку є якість атмосферного повітря, оскільки вона безпосередньо впливає на здоров'я людей, які проживають у регіонах з підвищеним рівнем техногенного навантаження. З'ясовано, що цементне виробництво є одним із головних джерел викидів шкідливих речовин, зокрема вуглекислого газу ($CO_2$) та твердих частинок (пилу), які формують аеродисперсні системи. Охарактеризовано закономірності поширення цементного пилу, що утворюється внаслідок промислового виробництва цементу, та його структуру як аеродисперсної системи, в якій дисперсною фракцією є тверді частинки або дрібнодисперсні краплі, а дисперсійною фазою – газоповітряна суміш, яка може містити різні забруднювальні речовини. Оцінено вплив цементного пилу на навколишнє середовище та здоров'я людей, що проживають у районах, прилеглих до цементних заводів, зокрема за допомогою довготривалого моніторингу концентрацій пилу в атмосфері. Встановлено, що моделювання процесу розповсюдження цементного пилу є ефективним методом для прогнозування концентрацій пилу в повітрі на різних відстанях від джерела викидів, що дає змогу розробляти конкретні заходи для зниження техногенного впливу на довкілля. Оцінено вплив моніторингу якості повітря на розроблення стратегій для покращення екологічної ситуації та зниження ризиків для здоров'я населення. Виявлено, що цементний пил є одним із пріоритетних забруднювачів, які необхідно враховувати під час організації ефективного атмосферного моніторингу для своєчасного реагування на зміни рівня забруднення. З'ясовано, що вдосконалення пиловловлювального обладнання на цементних заводах дає змогу зменшити викиди цементного пилу в атмосферу на 10-15 %, що є важливим етапом для забезпечення екологічної безпеки та покращення загальної якості життя населення.

**Ключові слова:** сталий розвиток; аеродисперсні системи; моніторинг якості повітря; математичне моделювання.