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APPLICATION OF DOMESTIC GAS ANALYZERS FOR MEASURING PM CONCENTRATION IN ATMOSPHERIC AIR

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Abstract
Environmental monitoring is one of the key elements to ensure the most effective security measures in various areas of life. The most famous technology in this field is the gas detection system within the framework of atmospheric air monitoring. It serves not only for an early warning program, but also for a constant check of the state of the atmosphere in certain areas. In the guidelines of the World Health Organization (WHO), updated in 2005, solid particles (dust or suspended substances) are among the main indicators of atmospheric air quality. According to the requirements of Directive 2008/50/EC of the European Parliament and the Council of 05.21.2008 on atmospheric air quality and cleaner air for Europe Ukraine should establish zones and agglomerations according to the degree of atmospheric air pollution throughout its territory, as well as the procedure for their review. In general, the goal set by the Directive is extremely difficult for Ukraine - to create a European monitoring system with modern equipment, which is a reliable tool for the development and implementation of environmental policy, on the remains of the air pollution control network that was created back in Soviet times. Nowadays gas sensors can be divided into two categories: conductive metal oxides and electrochemical, with the latter gaining more recognition over the last decade as the future standard component in any gas sensor. The paper presents the complete concept of an electrochemical gas sensor, including the basic science and basic electronic engineering that go into the device. The main focus is on a specific type of amperometric sensors as the most promising electrochemical sensor on the Ukrainian market. That is why the scientific novelty of the article lies in the fact that for the first time, on the basis of analysis and theoretical generalizations, it is proposed to create a program for the production of devices specifically for continuous automatic monitoring of atmospheric air quality. The practical value of the article lies in the systematization of scientific ideas regarding the monitoring of PM, which should become the basis for initial measures aimed at reducing emissions, which will increase the efficiency of management decision-making and improve the efficiency of the DSMD at all levels.
Key words: environmental monitoring, suspended substances, PM, dust meter, gas analyzer, dust measurement methods.

Problem statement

Clean and safe atmospheric air is a public value and the last free natural resource that for the majority of the population has no alternative to consumption. In September 2021, the World Health Organization (WHO) released new air quality guidelines that provide clear evidence of the harm that air pollution causes to human health, even at lower concentrations than previously thought [1]. According to WHO experts, every year air pollution causes up to 7 million premature deaths and leads to the loss of millions of healthy years of life. Therefore, improving the effectiveness of environmental monitoring of atmospheric air is an urgent issue [2].

Analysis of recent researches and publications

Currently, only the first steps are being taken in Ukraine to systematically monitor the concentrations of PM10 and PM2.5, as well as formaldehyde in atmospheric air. Methods are emerging and the organization of PM10 and PM2.5 monitoring has been started in the country's major cities [3–10]. This problem is also considered in works [11–18]. At the same time, there are currently no approved methods for calculating PM10 and PM2.5 emissions for the main types of activities that are the cause of significant dust generation, including for road traffic. WHO pays great attention to the hygienic value of fine particles.

Statement of the problem and its solution

The main task of the article is the issue of improving environmental monitoring of atmospheric air by expanding fixed PM measurements using gas analyzers of domestic production, which are designed for mobile use, work in extreme measurement conditions, and are stable and reliable.

In order to accurately assess the degree of pollution impact on humans in densely populated, complex urban areas and to reduce this risk to health, comprehensive information on spatio-temporal variations in concentrations of pollutants in atmospheric air, dominant sectors of emission sources, chemical processes and the role of meteorological conditions in accumulation and dispersion of pollution is necessary. Qualitative measurements of the concentration of pollutants in the air in real time can provide the necessary information.

One of the most important pollutants in the atmospheric air are suspended substances that are constantly present in the atmospheric air in the form of persistent aerosols, significantly affecting the homeostasis of the human body both as independent factors and indirectly as carriers of pathogenic microflora.

A single classification of particles suspended in the air has not been created. Their size fractions in air are most often used:

- TSP (total suspended solids): includes all particles in the air;
- PM10: used for particles with an aerodynamic diameter of less than 10 μm;
- PM2.5: used for particles with an aerodynamic diameter of less than 2.5 μm;
- Coarse fraction (between 2.5 and 10 μm);
- the smallest particle: used for particles with an aerodynamic diameter of less than 0.1 μm.

In a calm air environment, large dust particles (10…100 μm) settle quickly. Particles up to 0.1 μm practically do not settle and are in a state of constant Brownian motion and are able to spontaneously connect with each other.

The purpose of the article is to increase the level of environmental safety of atmospheric air by intensifying measurements of the concentration of fine organic particles using the Air Expert Mini device.

To achieve the specified goal, the following tasks must be solved:
- to analyze the ecological danger of emissions of finely dispersed organic solid particles;
- to analyze the main equipment and methods of measuring dust concentrations and particle sizes;
- to offer a new generation of mobile gas analyzers of the AirExpert series for monitoring PM.

1. Impact of PM on health

PM and public health data consistently indicate adverse health effects at the exposure levels experienced by urban dwellers worldwide, both in developed and developing countries. As a result of WHO's analysis of the impact of PM on health in large cities around the world [19], it was concluded that the impact of PM is the cause of almost 800,000 premature deaths per year. A similar analysis conducted within the framework of the European Commission program "Clean Air for Europe" [20] showed that PM from anthropogenic sources in all countries of the European Union is the cause of almost 290 thousand premature deaths per year. Exposure to these substances reduces the average life expectancy by about one year. It causes a wide range of consequences, including the respiratory and cardiovascular systems, applies to children and adults and a number of large sensitive population groups. The risk of various diseases has been shown to be proportional to exposure, and there is virtually nothing to indicate the existence of any concentration threshold below which no adverse health effects can be assumed. Epidemiological data indicate negative effects of particles after short-term (lasting a few days) and long-term (lasting years) exposure.

In the majority of epidemiological studies [21–25], which demonstrated the negative impact of PM on health, PM10 concentration per unit mass was used as an indicator of the level of exposure. Respiratory tract morbidity is associated with the coarse PM10 fraction (i.e., particles with a size of 2.5 to 10 μm). However, the closest relationship between mortality from cardiovascular diseases and long-term exposure to PM was observed for the concentration of PM2.5, and not for larger particles. Therefore, reducing the exposure to PM10 and PM2.5 is recommended as a necessary measure to reduce the threat of many health consequences. Particles larger than PM10 remain in the upper respiratory tract and do not affect morbidity and mortality. From the conclusions of the study, it follows that the relation to health care, air quality management should primarily be aimed at reducing the population's exposure to PM2.5 and PM10. For this, it is necessary to estimate PM2.5 and PM10 concentrations. Monitoring the concentration of total suspended solids, or TSP (which includes particles larger than PM10) is less suitable for effective regulation of air quality for public health purposes.

Since the end of the 90s in Europe as a result of the introduction of mandatory standards and regulations, considerable experience has been accumulated in monitoring and evaluating the content of PM10, but there is much less experience and information on PM2.5 [26]. In WHO research related to health issues, it is recommended to evaluate both PM10 and PM2.5 to assess exposure to PM and the health threats it poses. In the currently discussed project of amendments to the Directive of the European Union on air quality, it is planned to reduce the impact on the population of PM2.5. In the USA, the air quality standard applies to PM2.5, but the coarse PM fraction (2.5…10) is also under control.

Different countries have different approaches to establishing MPCs of harmful substances in atmospheric air, to determining air quality targets and other standards. But, despite the different approaches for many substances, the numerical values of the indicators are quite close (Table 1).

Table 1 - Atmospheric air quality standards: EU, WHO

Pollutant	Averaging period or nature of standard	Concentrations, μg/m^3	
		EU	WHO
Suspended matter, particles <10 μm in size (PM10)	24 hours	50	50
	A year	40	20
Suspended matter, particles <2.5 μm in size (PM2.5)	24 hours	–	20
	A Year	25	10
Suspended solids (total concentration)	24 hours	–	–
	20 minutes	–	–

The general objective of the air quality management strategy is to prevent and reduce negative consequences for human health (and for the environment as a whole) caused by the presence of pollutants in the air, in particular suspended substances [27]. To protect human health, it is necessary to reduce, prevent, and if possible avoid exposure of the population to PM.

According to [28], the atmospheric air quality management body is responsible for atmospheric air quality in zones and agglomerations.

For a reliable assessment of atmospheric air pollution by suspended substances, objective observational data are required by correctly determining the characteristics of PM levels, the pattern of spatial and temporal distribution and composition of PM. For this, monitoring and/or modeling programs are used, as well as forecasting of air quality in the future in case of implementation of alternative strategies.

2. Equipment for measuring dust concentrations and particle sizes [29, 30]

The assessment of PM content leads to the accumulation and systematization of data on PM concentrations in different ranges of time and space. A meaningful comparison of such data, obtained from different places and/or at different times, is possible only if the monitoring data are of high quality, represent the same variable and are presented uniformly. And this is possible only when using commonly agreed methods in all cases. The results of various existing PM10 monitoring methods have systematic differences, and each of these methods has its advantages and disadvantages, which should be taken into account when designing a monitoring network.

In most devices, atmospheric air is taken in through a specially designed inlet device (air intake), which lets in only the PM10 fraction. By changing the air intake, you can measure PM2.5 instead of PM10. To estimate the mass concentration (μg/m^3), it is necessary to adjust the air flow (volume per second) taking into account the temperature and pressure of the atmospheric air.

2.1. Manual sampling and gravimetry

When sampling manually:

- atmospheric air is drawn through the filter at a constant flow rate. The particles are collected on the filter. The mass of the particles is determined by weighing;
- filters are weighed before and after sampling; the difference in mass is the mass of the particles. In both cases, the filters must be equilibrated in an air-conditioned weighing room before each weighing;
- the sampling period is usually 24 hours. The sampling period and flow rate allow the volume of each sample to be calculated. The volume is calculated by multiplying the flow rate by the sampling period;
- manipulations with each filter before the beginning and after the end of each test should be carried out manually [31].

2.2. Methods of measuring dust in atmospheric air

A dust meter is a device designed to measure the mass concentration of dust in the flue gases of fuel-burning plants, in working and living areas, in atmospheric air. A certain type of device must be used for each task.

Today, there are several methods of measuring dust: optical (photometric), gravimetric, piezobalance, triboelectric, radioisotope. Let's consider each of them [32]:

1) Optical method of dust measurement (photometric and nephelometric method).

The optical principle of action is in measuring the weakening of the intensity of light radiation when it passes through a dusty environment. The concentration of dust particles is proportional to the value of the optical density, which is determined automatically and is the negative decimal logarithm of the transmission coefficient.

Disadvantages of the photometric absorption method:

- low sensitivity when measuring small concentrations of aerosol particles (less than 30 mg/m³), as well as the impossibility of controlling high concentrations (over 12 g/m³) due to almost complete absorption of light radiation;
- high impact of physical and chemical properties of aerosols on the measurement result (size, composition and color of the aerosol);
- the need for periodic cleaning of optical elements (optics, reflectors, etc.)

When measuring small concentrations of aerosol particles, the nephelometric method, based on the registration of direct, side and backscattered light radiation, turns out to be much more effective.

The disadvantage of the nephelometric method of direct scattering when controlling the weight concentration of dust aerosols with a wide dispersed composition is a sharp loss of sensitivity when measuring concentrations of particles with a diameter of more than 8-10 microns, which significantly reduces and even eliminates the possibility of their application in many industries. Therefore, these devices are used mainly where fine aerosol particles are emitted.

2) The gravimetric method of aerosol measurement consists in the separation of particles from the dust and gas flow, followed by their deposition on an analytical filter and drying. The mass concentration of the aerosol is determined by the amount of growth on the filter, taking into account the volume of the sample. The dust concentration in this case is calculated using the formula.

The advantages of this method are the accuracy of the measurement, since the aerosol is directly measured and there is no influence of physicochemical properties on the results.

Disadvantages of the gravimetric method:

- laboriousness of the method;
- duration of the process;
- use of additional equipment.

3) The time-consuming gravimetric method was replaced by a new method of piezobalance weighing of the deposited dust sample. This method was first implemented in pile meters of the KANOMAX company in models 3521 and 3522 [33]. The piezobalance method of measuring the operation of the device consists in periodic sampling of aerosol particles through an impactor, which separates respiratory (up to 10 μm) fractions from the total mass of particles, in their further charging on the crown electrode and then deposition on the surface of the sediment electrode. A piezoelectric element (quartz) is used as such an electrode. The sampling is carried out by the internal pump of the device. A quartz piezo element is included in the circuit of the electric oscillation generator. When dust settles on its surface, the weight of the piezo element changes and, as a result, the frequency of its

oscillations does as well. The change in frequency depends linearly on the mass of the dust falling on the element and is the value of the measured weight concentration of the aerosol.

Advantages of the piezobalance measurement method:

- fast performance of measurements, there is no need to use a large fleet of additional equipment;
- reliability of device readings, physical and chemical properties do not affect measurements;
- small dimensions of the measuring instrument.

Disadvantages of the piezobalance measurement method:

- measurement is carried out only in working and living areas;
- expensive equipment;
- careful operation is required (the sensitive element of the device is very fragile, falling down is not allowed).

4) The triboelectric measurement method is based on the measurement of the induced charge on an isolated measuring electrode located in a metal gas duct along which the dust flow moves. The induced charge occurs when mobile aerosol particles interact with the electrode surface, and its value is proportional to the mass concentration of the aerosol in a wide range of measurements.

These devices are called triboelectric. They can be divided into devices that measure the constant component of the triboelectric signal and devices that measure the variable component of the triboelectric signal (electrodynamic induced charge).

Advantages of the triboelectric measurement method:

- vibration at the installation site does not affect the readings;
- does not have nodes that can get dirty, which allows you to use the devices for a long time in harsh conditions;
- there are no nodes in the device that produce their resource with the expiration of time. The devices are durable, due to which they become simple and cheap to maintain.

5) The radioisotope method of measuring dust concentration is based on the property of radioactive radiation (usually β-radiation) to be absorbed by dust particles. The mass of captured dust is determined by the degree of attenuation of radioactive radiation when it passes through a layer of accumulated dust [34].

3. A new generation of mobile gas analyzers of the AirExpert series

Currently, many European cities are implementing large-scale programs to improve the quality of atmospheric air [35], in particular, developed programs to create a new generation of inexpensive mobile gas analyzers (based on Alphasense Ltd sensors) in addition to existing stationary monitoring stations. Similar equipment is being developed and tested in Ukraine. The devices of the AirExpert series, corresponding to European levels, which have been tested and prepared for release can be offered as one of the mobile operational control options for use.

As a result of the work carried out on the development of a new generation of gas analyzers, inexpensive devices for monitoring the concentration of harmful chemicals in the ppb range in the atmospheric air of populated areas, the development of the domestic device Air Expert, which is not inferior in its characteristics to the best world analogues, is being completed.

Air Expert (factory code name “IKGM-14 gas analyzer”) is designed for measuring the volume fraction or mass concentration of pollutants in the air.

Air Expert can be used to control the concentration of pollutants in the air of populated areas and in the air of the working area. Air Expert can be integrated into mobile, object and regional production and environmental monitoring systems of potentially dangerous objects and the environment.

When performing the main function of measuring the concentration of pollutants in the air, the device can perform the following functions:

- measuring the concentration of pollutants in the air;
- setting alarm thresholds within the entire range of measurements, including in the area of maximum permissible concentrations (MPC);
- formation of signs of exceeding the threshold values of concentrations of pollutants in the air;
- automatic change of measurement and data transfer modes depending on the measured values of the concentration of pollutants;
- autonomous storage of data in the built-in non-volatile memory;
- data transmission via various wireless communication channels at a distance of up to 100 km (SkyLINK) and more (GSM / GPRS - globally), other communication channels at shorter distances.

Additional features:

- determination and transmission of GPS / GLONASS coordinates;
- quality control of measurement results and data transmission;
- measurement and registration of meteorological parameters:
- air temperature;
- relative air humidity;
- atmospheric pressure;
- the possibility of connecting an external weather station for measuring additional meteorological parameters;
- control of the voltage of the built-in power source, estimation of the remaining time of continuous autonomous operation;
- indication of measurement results on the built-in display (implemented in subsequent modifications);
- indication of measurement results on the external panel (implemented in subsequent modifications).

3.1. Principle of device operation

The concentration of each pollutant is measured using a detector consisting of one or two (depending on the modification of the gas analyzer) sensors. The measured values are stored in the built-in memory, compared with the MPC and transmitted via the cellular network (SkyLINK, GSM / GPRS, etc.) for further processing and archiving in specialized software [36].

The appearance of the device is shown at Fig. 1 [37].

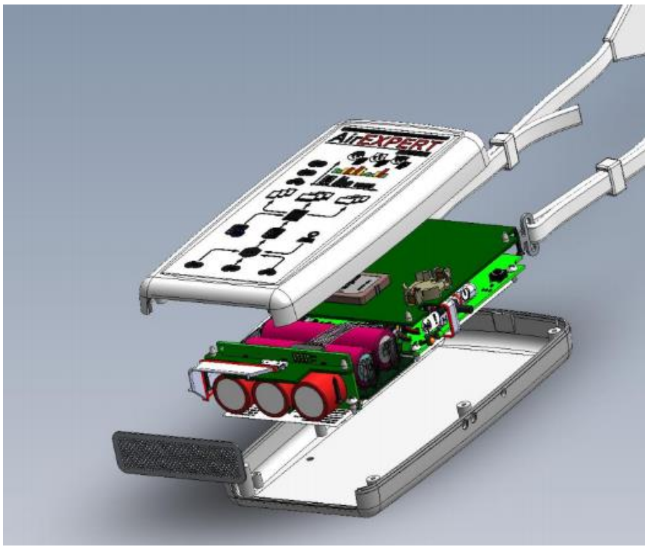

Figure 1 - Appearance of the Air Expert Mini device

The mobile dust meter of the AirExpert Mini PM series is designed to measure the concentration of dust fractions PM1, PM2.5, PM10 (additionally PM4.25) in the atmospheric air of populated areas, as well as indoors, measures particle sizes 0.35…12.4 microns, in the concentration range of 0.01 μg/m^3 – 1,500 μg/m^3, 0…95 % humidity, at temperatures –10…+50ºC.

Pumping speed 0.24 l/min., distribution of particles in 16 hoppers, has built-in temperature and humidity sensors both inside the OPC-R1 dust sensor and at the environmental measurement point. The measured data is transmitted via the GSM channel, there is a built-in GPS receiver, and the data is stored on a cloud (or physical) server, where AirExpert Visio software is used to collect, store, processing and presentation of data with mapping of the terrain of the movement route and construction of temporary schedules for all fractions of dust. The size of the mobile gas analyzer is 194x95x17 mm, weight – about 380 g. The time of continuous autonomous operation is up to 24 hours. Measurement error: ±15 % according to TSI 3330. Measurement method defined by the European standard EN 481.

Mobile pile meters of the AirExpert Mini PM/PM Pro series can be used:

- to solve the task of mapping the spatio-temporal distribution of the concentration of harmful chemicals and dust in populated areas (as required by the programs for creating monitoring networks of zones and agglomerations [38]) with the creation of relevant databases and the use of these data to reduce the incidence of population diseases caused by harmful chemicals from transport and industry;
- for measuring the concentrations of dust fractions, coordinates, time, when mapping the atmospheric air of populated areas with the creation of pollution maps of the area as additional information to the data measured by stationary pollution posts of the state network of atmospheric air monitoring;
- mapping the distribution of ragweed plants for early warning of the inevitable high level of pollen;
- for measuring concentrations of dust fractions in residential buildings, public buildings and places of mass gathering of people (kindergartens, schools, educational institutions, individual housing);
- to conduct epidemiological studies of cardiovascular and respiratory diseases of various population groups and individual citizens, analyzing atmospheric air pollution in cities and rural areas, indoors and outdoors;
- the use of a new generation of mobile pilemeters of the AirExpert Mini PM series is possible for the assessment of personal doses of various air pollutants in large-scale studies of public health.

The main competitive advantages of using the AirExpert Mini PM/PM Pro series pile meter:

- the mobile gas analyzer of the AirExpert Mini PM/PM Pro series was developed taking into account the recommendations of the World Health Organization, the World Meteorological Organization, and the UN Environment Program;
- imprecise quantification of personal exposure to air pollution introduces error and bias into population health assessments, severely limiting causal inferences in epidemiological studies worldwide. Rapid advances in affordable, mobile, compact AirExpert Mini PM/PM Pro series air pollution meters offer the potential to overcome this limitation by accounting for the high variability of personal exposure in everyday life in large-scale studies with unprecedented spatial and temporal distribution;
- compared to traditional methods of monitoring solid particles (PM), the price advantage and minimal maintenance of inexpensive mobile pilemeters of the AirExpert Mini PM/PM Pro series make them a promising addition to modern monitoring methods. They can increase the spatio-temporal resolution of pollution maps, increase the accuracy of personal exposure assessment and the variation of PM transport patterns. Accurate assessment of personal exposure to PM can benefit epidemiological studies by identifying adverse health effects of PM. Improving and understanding PM transport patterns can effectively control and even prevent pollution;
- the use of AirExpert Mini PM/PM Pro mobile pilemeters is an important tool for understanding the sources, processes and consequences of air pollution for human health.

Conclusions.

Thus, today we can say that Ukraine is ready to move to mass production of domestic gas analyzers of the new generation, but for this our state must overcome a number of obstacles, among which the following are important:

- there is no state customer in Ukraine;
- the ideology of monitoring the atmospheric air of populated areas and dust with the help of a new generation of gas analyzers is not realized as an addition to the existing state surveillance network;
- the impossibility of one private enterprise to carry out costly work on the creation and serial production of

a new generation of mobile and stationary gas analyzers without the participation of state organizations;

- capture of the Ukrainian market by foreign firms that started in this direction 5 years ago and concentrated scientific and financial resources, the use of foreign equipment usually offers storage of measurement data on foreign servers;

- there are no enterprises producing a new generation of sensors for measuring the concentration of harmful chemicals ppb.

The use of gas analyzers of the AirExpert type can serve for comprehensive monitoring of PM and be the basis for initial measures aimed at reducing emissions. Therefore, even before the creation of observation networks with stationary observation measuring posts, which are much more expensive than AirExpert, it is recommended to start operating such devices as soon as possible for continuous automatic observation of concentrations of PM and their trends. Such gas analyzers allow you to roughly determine the quality of atmospheric air in the measurement area, and based on this data, you can choose the location of the APS (measuring or indicative) with maximum accuracy.

Thus, in accordance with the General Strategy for Reducing the Negative Effects of Air Pollution on Health in EECCA countries, it is necessary to create a program for the production of devices for continuous automatic monitoring of atmospheric air quality in Ukraine, as well as all consumables and additional equipment for installation, protection and operation in as part of a set of devices for complex environmental monitoring systems at the state and regional levels.

REFERENCES

1. World Health Organization. (2021). *WHO global air quality guidelines. Particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide*. WHO European Centre for Environment and Health, 273. URL: https://iris.who.int/bitstream/handle/10665/345329/9789240034228-eng.pdf.

2. *Dyrektyva 2008/50/EC Yevropeiskoho Parlamentu ta Rady vid 21 travnia 2008 roku pro yakist atmosfernoho povitria ta chystishe povitria dlia Yevropy*. [*Directive 2008/50/EC of the European Parliament and of the Council of May 21, 2008 on ambient air quality and cleaner air for Europe*]. URL: https://zakon.rada.gov.ua/laws/show/994_950#Text. [in Ukrainian]

3. Dmytriieva, O. O., Varlamov, Ye. M., Kvasov, V. A., Palahuta, O. A., Nesterenko, L. M., & Nesterenko, U. Iu. (2016). Stan merezhi sposterezhennia za atmosfernym povitriam v Ukraini ta yii vidpovidnist vymoham Dyrektyvy 2008/50/IeS [The state of the air monitoring network in Ukraine and its compliance with the requirements of Directive 2008/50/EU]. *Problemy okhorony navkolyshnoho pryrodnoho seredovyshcha ta ekolohichnoi bezpeky*, 38, 99–110. [in Ukrainian]

4. Kondratenko, O. M., Andronov, V. A., Polishchuk, T. R., Kasionkina, N. D., & Krasnov, V. A. (2022). Accounting the emissions of engine fuel vapors in the criteria-based assessment of the ecological safety level of power plants with reciprocating ICE exploitation process. *Dvyhuny vnutrishnoho zghoriannia*, 1, 40–50. DOI: 10.20998/0419-8719.2022.1.06.

5. Strokov, O. P., Kondratenko, O. M., Koloskov, V. Yu., & Mishchenko, I. V. (2019). Description of mass hourly emissions of particulate matter of diesel engine by beta-distri-bution with taking into account the passport accuracy of gas analyzer. *Dvyhuny vnutrishnoho zghoriannia*, 1, 49–62. DOI: 10.20998/0419-8719.2019.1.09.

6. Kondratenko, O., Andronov, V., Koloskov, V., & Strokov, O. (2021). Development and Use of the Index of Particulate Matter Filter Efficiency in Environmental Protection Technology for Diesel-Generator with Consumption of Biofuels. *IEEE KhPI Week on Advanced Technology: Conference Proceedings (13–17 September 2021, NTU «KhPI», Kharkiv)*, 239–244. DOI: 10.1109/KhPIWeek53812.2021.9570034.

7. Kondratenko, O. M., Andronov, V. A., Koloskov, V. Yu., Tkachenko, O. O., & Kapinos, Ye. V. (2021). Determination of reference values of complex fuel and ecological criterion as the separate independent factor of ecoloical safety. *Dvyhuny vnutrishnoho zghoriannia*, 1, 75–85. DOI: 10.20998/0419-8719.2021.1.10.

8. Kondratenko, O. M., Koloskov, V. Yu., Kovalenko, S. A., Derkach, Yu. F., Botsmanovska, O. S., & Podolyako, N. M. (2020). Determination of emissions of vapor of technic flammable liquids from enterprise for their storing and distribution and rational adjustments of their breathing valves. *Technogenic and Ecological Safety*, 8(2/2020), 17–31. DOI: 10.5281/ zenodo.4300753.

9. Kondratenko, O. M., Andronov, V. A., Strokov, O. P., Babakin, V. M., & Krasnov, V. A. (2022). Instrumentalna pokhybka vidomykh formul pererakhunku pokaznykiv dymnosti u pokaznyky toksychnosti vidpratsovanykh haziv porshnevykh DVZ [Instrumental error of known formulas for converting smoke values into toxicity values of exhaust gases of reciprocating internal combustion engines]. *Technogenic and ecological safety*, 12(2/2022), 3–18. DOI: 10.52363/2522-1892.2022.2.1. [in Ukrainian].

10. Kondratenko, O. M., Koloskov, V. Yu., Tkachenko, O. O., Kapinos, Ye. V., & Repetenko, M. V. (2021). Development of the combined reservoir of mixture of technical combustible liquids as component of environment protection technology. *Technogenic and Ecological Safety*, 10(2/2021), 28–40. DOI: 10.52363/2522-1892.2021.2.5.

11. Kondratenko, O., Koloskov, V., Kovalenko, S., Derkach, Y., & Strokov, O. (2020). Criteria based assessment of efficiency of conversion of reciprocating ICE of hybrid vehicle on consumption of biofuels. *IEEE KhPI Week on Advanced Technology, KhPI Week 2020. 05–10 October – Conference Proceedings*, 177–182. DOI: 10.1109/KhPIWeek 51551.2020.9250118.

12. Vambol, S., Vambol, V., Kondratenko, O., Suchikova, Y., & Hurenko, O. (2017). Assessment of improvement of ecological safety of power plants by arrangement of pollutants neutralization system. *Eastern-European Journal of Enterprise Technologies*, 3/10 (87), 63–73. DOI: 10.15587/1729-4061.2017.102314.

13. Kondratenko, O. M., Chernobay, G. O., Derkach, Ju. F., & Kovalenko, S. A. (2019). Features of determination of the efficiency of devices for improvement of ecological safety level of vehicles with reciprocating ICE exploitation. *Dvyhuny vnutrishnoho zghoriannia*, 2, 36–44. DOI: 10.20998/0419-8719.2019.2.07.

14. Kondratenko, O. M. (2020). Assessment of ecological and chemical efficiency of exploitation process of reciprocating ICE of vehicle with concideration of emission of sulphur oxides, benzo(a)pyrene and polycyclic aromatic hydrocarbones. *Technogenic and Ecological Safety*, 7(1/2020), 38–50. DOI: 10.5281/zenodo.3780076. [in English].

15. Kondratenko, O. M. (2019). Taking into account the emissions of CO2 as a toxic pollutant and as a greenhouse gas in fuel and ecological complex criteria-based assessment of diesel-generator operation process. *Technogenic and Ecological Safety*, 6(2/2019), 12–23. DOI: 10.5281/zenodo.3558960.

16. Kondratenko, O. M., Strokov, O. P., Vambol, S. O., & Avramenko, A. M. (2015). Matematychna model efektyvnosti roboty filtra tverdykh chastynok dyzelia [Mathematical model of diesel particulate filter efficiency]. *Naukovyi visnyk NHU*, 6 (150), 55–61. [in Ukrainian].

17. Kondratenko, O., Mishchenko, I., Chernobay, G., Derkach, Yu., & Suchikova, Ya. (2018). Criteria based assessment of the level of ecological safety of exploitation of electric generating power plant that consumes biofuels. *2018 IEEE 3rd International Conference on Intelligent Energy and Power Systems (IEPS–2018): Book of Papers*, 57-1–57-6. DOI: 10.1109/IEPS.2018.8559570.

18. Vambol, S. O., Vambol, V. V., Kondratenko, O. M., & Mishchenko, I. V. (2018). *Kryterialne otsiniuvannia rivnia ekolohichnoi bezpeky protsesu ekspluatatsii enerhetychnykh ustanovok* [*Criterion assessment of the level of environmental safety of the process of operation of power plants*]. Kh.: NUTsZU, Styl-Yzdat. [in Ukrainian]

19. Turos, O. I., Petrosian, A. A., Davydenko, H. M., Blyzniuk, V. V., Anatolieva, O. V., & Sevalniev, A. I. (2012). Analiz otsinky sotsialnykh vtrat zdorovia naselennia, obumovlenykh zabrudnenniam atmosfernoho povitria (na prykladi vykydiv ZCh10) [Analysis of the assessment of social losses of public health caused by atmospheric air pollution (on the example of PM10 emissions).]. *Hihiiena naselenykh mists*, 59, 52–57. [in Ukrainian]

20. *Plan dii shchodo zmenshennia promyslovoho zabrudnennia povitria u mistakh Ukrainy*. *Ohliad variantiv polityky ta rekomendatsii* [*Action plan to reduce industrial air pollution in Ukrainian cities. Overview of policy options and recommendations*]. (2020). URL: cleanair.org.ua-o-chyste-povitrya-dlya-ukrayiny-2020.pdf. [in Ukrainian]

21. *Particulate Matter (PM) Pollution. United States Environmental Protection Agency*. URL: https://www.epa.gov/pm-pollution/particulate-matter-pm.

22. *Ambient air quality and cleaner air for Europe: Directive of the European Parliament and of the Council of 21 May 2008*. URL: https://eur-lex.europa.eu/EN/legal-content/summary/cleaner-air-for-europe.html.

23. *Ambient air pollution: a global assessment of exposure and burden of disease* / director of Public Health, Environmental and Social Determinants of Health. URL: https://apps.who.int/iris/bitstream/handle /10665/250141 /9789241511353-eng.pdf.

24. Turos, O. I., Maremukha, T. P., & Kobzarenko, I. V. (2017). Zabrudnennia atmosfernoho povitria zvazhenymy chastynkamy pylu (ZCh10 ta ZCh2,5) u Desnianskomu raioni m. Kyieva [Atmospheric air pollution by suspended dust particles (PM10 and PM2.5) in the Desnyan district of Kyiv]. *Hihiiena naselenykh mists*, 67, 32-33. [in Ukrainian].

25. *Assessment of the health impacts of exposure to PM2,5 at a European level. ETC/ACC Technical Paper*. (2009). URL: https://acm.eionet.europa.eu/d ocs/ ETCACC_TP_2009_[in English].

26. Vambol, S. O., Vambol, V. V., Suchikova, Y. O., Mishchenko, I. V., & Kondratenko, O. M. (2017). *Scientific and practical problems of application of ecological safety management systems in technics and technologies*. Opole: Publ. Academy of Management and Administration.

27. *Pro Osnovni zasady (stratehiiu) derzhavnoi ekolohichnoi polityky Ukrainy na period do 2030 roku* [*On the Basic Principles (Strategy) of the State Environmental Policy of Ukraine for the Period Until 2030*]. 2697-VIII Law of Ukraine. (2019). URL: https://ips.ligazakon.net/document/T192697. [in Ukrainian]

28. *Deiaki pytannia zdiisnennia derzhavnoho monitorynhu v haluzi okhorony atmosfernoho povitria* [*Some issues of state monitoring in the field of atmospheric air protection*]. 827 Order of the Cabinet of Ministers of Ukraine. (2019). URL: https://zakon.rada.gov.ua/laws/show/827-2019-%D0%BF#Text. [in Ukrainian]

29. *Vymiriuvannia pylovykh chastynok* [*Measurement of dust particles*]. URL: https://www.gastech.com.ua/vymiryuvannya-palevyh-chastynok/. [in Ukrainian]

30. Hichov, Yu. O. (2015). *Ochyshchennia haziv* [*Gas purification*]. Dnipropetrovsk: NMetAU. URL: https://nmetau.edu.ua/file/21._gichov_yu.o._ochischennya_gaziv._chastina_i.pdf. [in Ukrainian]

31. World Health Organization. (2020). *Ruchnyi vidbir prob* [*Manual sampling*]. URL: https://www.euro.who.int/__data/assets/pdf_file/0020/130763/E88565R.pdf [in Ukrainian].

32. Holinko, V. I., & Shybka, M. V. (2013). *Metodychni vkazivky do laboratornoi roboty «Vyvchennia metodiv i zasobiv kontroliu zapylenosti povitria» z dystsypliny «Osnovy okhorony pratsi» dlia studentiv usikh spetsialnostei* [*Methodological instructions for the laboratory work "Study of methods and means of air dust control" from the discipline "Fundamentals of occupational health and safety" for students of all specialties*]. Derzhavnyi VNZ «Natsionalnyi hirnychyi universytet», 16. URL: https://aop.nmu.org.ua/ua/metodicki/bakalavr/oop/lp/%D0%9F%D1%8B%D0%BB%D1%8C.pdf. [in Ukrainian]

33. *Piezobalansnyi vymiriuvach masovoi kontsentratsii pylu KANOMAX 3521 / 3522* [*KANOMAX 3521 / 3522 piezo-balance dust mass concentration meter*]. URL: https://eco-intech.com/product/pezobalansnyy-izmeritel-massovoy-kontsentratsii-respirabelnoy-pyli-kanomax-3521-3522/. [in Ukrainian]

34. Hryha, V. M., Humenytskyi, M. B., Sachovskyi, A. M., & Rudyk, R. D. (2020). *Avtomatyzovanyi prystrii kontroliu yakosti povitria NS* [*Automated air quality control device of the National Emergency*]. Ivano-Frankivsk: DVNZ "Prykarpatskyi natsionalnyi universytet im. V. Stefanyka". URL: https://kkite.pnu.edu.ua/wp-content/uploads/sites/50/2020/05/ATSU2020_T1_P104.pdf. [in Ukrainian]

35. Ecoaction. (2022). *Upravlinnia yakistiu atmosfernoho povitria v krainakh Yevropy* [*Air quality management in European countries*]. URL: https://ecoaction.org.ua/upravlinnia-iakistiu-atm-povitria-u-evropi.html. [in Ukrainian]

36. *Mobilni standarty. Tsikavo znaty* [*Mobile standards. Interesting to know*]. URL: https://elmir.ua/articles/mobil_nye_standarty_eto_interesn.html. [in Ukrainian]

37. *Ofitsiina storinka kompanii "Pozitron GMBH"* [*The official page of the company "Positron GMBH"*]. URL: http://www.positron.dp.ua/. [in Ukrainian]

38. *Pro zatverdzhennia formy Prohramy derzhavnoho monitorynhu u haluzi okhorony atmosfernoho povitria* [*On approval of the form of the state monitoring program in the field of atmospheric air protection*]. 147 Order of the Ministry of Environmental Protection and Natural Resources of Ukraine. (2021). URL: https://ips.ligazakon.net/document/RE36165. [in Ukrainian]

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ЗАСТОСУВАННЯ ВІТЧИЗНЯНИХ ГАЗОАНАЛІЗАТОРІВ ДЛЯ ВИМІРЮВАНЬ КОНЦЕНТРАЦІЇ PM В АТМОСФЕРНОМУ ПОВІТРІ

Моніторинг довкілля є одним із ключових елементів для забезпечення найбільш ефективних заходів безпеки в різних сферах життя. Найбільш відомою технологією в цій галузі є система виявлення газів у рамках моніторингу атмосферного повітря. Вона служить не лише для програми раннього попередження, а й для постійної перевірки стану атмосфери в певних зонах. У керівних принципах Всесвітньої організації охорони здоров’я (ВООЗ), оновлених у 2005 р., тверді частинки (пил або суспендовані речовини) відносяться до основних показників якості атмосферного повітря. Згідно з вимогами Директиви 2008/50/ЄС Європейського Парламенту та Ради від 21.05.2008 р. про якість атмосферного повітря та чистіше повітря для Європи Україна має встановити по всій своєї території зони та агломерації за ступенем забруднення атмосферного повітря, а також порядок їх перегляду. Загалом мета, поставлена Директивою, є для України надзвичайно складною – на залишках мережі контролю забруднення атмосферного повітря, що була створена ще за радянських часів, створити європейську систему моніторингу із сучасним обладнанням, яка є надійним інструментом розробки та реалізації природоохоронної політики. Сьогодні датчики газу розділяють на дві категорії: електропровідні оксиди металів та електрохімічні, причому останній отримав більше визнання протягом останнього десятиліття як майбутній стандартний компонент у будь-якому газовому датчику. У статті представлено повну концепцію електрохімічного датчика газу, включаючи фундаментальну науку та базову електронну інженерію, яка працює з пристроєм. Основна увага зосереджена на конкретному типі датчиків амперометричного типу як найперспективнішому електрохімічному датчику на ринку України. Саме тому наукова новизна статті полягає у тому, що вперше на основі аналізу та теоретичних узагальнень запропонованоно створити програму виробництва приладів конкретного безперервного автоматичного контролю якості атмосферного повітря. Практична цінність статті полягає у систематизації наукових уявлень щодо моніторингу PM, що має стати основою для початкових заходів, спрямованих на зниження викидів, що дозволить підвищити оперативність прийняття управлінських рішень та поліпшити ефективність роботи ДСМД на усіх рівнях.

Ключові слова: моніторинг довкілля, зважені речовини, PM, пиломір, газоаналізатор, методи вимірювання пилу.

ЛІТЕРАТУРА

1. WHO global air quality guidelines. Particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide / World Health Organization. WHO European Centre for Environment and Health, 2021. 273 p. URL: https://iris.who.int/bitstream/handle/10665/345329/9789240034228-eng.pdf (access date: 15.09.2023).
2. Директива 2008/50/ЄС Європейського Парламенту та Ради від 21 травня 2008 року про якість атмосферного повітря та чистіше повітря для Європи. URL: https://zakon.rada.gov.ua/laws/show/994_950#Text (дата звернення: 15.09.2023).
3. Дмитрієва О. О., Варламов Є. М., Квасов В. А., Палагута О. А., Нестеренко Л. М., Нестеренко У. Ю. Стан мережі спостереження за атмосферним повітрям в Україні та її відповідність вимогам Директиви 2008/50/ЄС. *Проблеми охорони навколишнього природного середовища та екологічної безпеки*. 2016. № 38. С. 99–110.
4. Accounting the emissions of engine fuel vapors in the criteria-based assessment of the ecological safety level of power plants with reciprocating ICE exploitation process / Kondratenko O. M. et al. *Двигуни внутрішнього згоряння*. 2022. № 1. С. 40–50. DOI: 10.20998/0419-8719.2022.1.06.
5. Description of mass hourly emissions of particulate matter of diesel engine by beta-distribution with taking into account the passport accuracy of gas analyzer / Strokov O. P., Kondratenko O. M., Koloskov V. Yu., Mishchenko I. V. *Двигуни внутрішнього згоряння*. 2019. № 1. С. 49–62. DOI: 10.20998/0419-8719.2019.1.09.
6. Development and Use of the Index of Particulate Matter Filter Efficiency in Environmental Protection Technology for Diesel-Generator with Consumption of Biofuels / Kondratenko O., Andronov V., Koloskov V., Strokov O. *2021 IEEE KhPI Week on Advanced Technology: Conference Proceedings (13–17 September 2021, NTU «KhPI», Kharkiv)*. 2021. Pp. 239–244. DOI: 10.1109/KhPIWeek53812.2021.9570034.
7. Determination of reference values of complex fuel and ecological criterion as the separate independent factor of ecoloical safety / Kondratenko O. M. et al. *Двигуни внутрішнього згоряння*. 2021. № 1. С. 75–85. DOI: 10.20998/0419-8719.2021.1.10.
8. Determination of emissions of vapor of technic flammable liquids from enterprise for their storing and distribution and rational adjustments of their breathing valves / Kondratenko O. M.et al. *Technogenic and Ecological Safety*. 2020. № 8(2/2020). Pp. 17–31. DOI: 10.5281/zenodo.4300753.
9. Інструментальна похибка відомих формул перерахунку показників димності у показники токсичності відпрацьованих газів поршневих ДВЗ / Кондратенко О. М. та ін. *Technogenic and ecological safety*. 2022. № 12(2/2022). С. 3–18. DOI: 10.52363/2522-1892.2022.2.1.
10. Development of the combined reservoir of mixture of technical combustible liquids as component of environment protection technology / Kondratenko O. M. et al. *Technogenic and Ecological Safety*. 2021. № 10(2/2021). Pp. 28–40. DOI: 10.52363/2522-1892.2021.2.5.
11. Criteria based assessment of efficiency of conversion of reciprocating ICE of hybrid vehicle on consumption of biofuels / Kondratenko O. Et al. *2020 IEEE KhPI Week on Advanced Technology, KhPI Week 2020. 05–10 October 2020. – Conference Proceedings*. 2020. Pp. 177–182. DOI: 10.1109/KhPIWeek 51551.2020.9250118.
12. Assessment of improvement of ecological safety of power plants by arrangement of pollutants neutralization system / Vambol S. et al. *Eastern-European Journal of Enterprise Technologies*. 2017. Vol, 3/10 (87). Pp. 63–73. DOI: 10.15587/1729-4061.2017.102314.
13. Features of determination of the efficiency of devices for improvement of ecological safety level of vehicles with reciprocating ICE exploitation / Kondratenko O. M., Chernobay G. O., Derkach Ju. F., Kovalenko S. A. *Двигуни внутрішнього згоряння*. 2019. № 2. С. 36–44. DOI: 10.20998/0419-8719.2019.2.07.
14. Kondratenko O. M. Assessment of ecological and chemical efficiency of exploitation process of reciprocating ICE of vehicle with conсideration of emission of sulphur oxides, benzo(a)pyrene and polycyclic aromatic hydrocarbones. *Technogenic and Ecological Safety*. 2020. № 7(1/2020). С. 38–50. DOI: 10.5281/zenodo.3780076.
15. Kondratenko O. M. Taking into account the emissions of CO2 as a toxic pollutant and as a greenhouse gas in fuel and ecological complex criteria-based assessment of diesel-generator operation process. *Technogenic and Ecological Safety*. 2019. № 6(2/2019). Pp. 12–23. DOI: 10.5281/zenodo.3558960.
16. Математична модель ефективності роботи фільтра твердих частинок дизеля / Кондратенко О. М., Строков О. П., Вамболь С. О., Авраменко А. М. *Науковий вісник НГУ*. 2015. № 6 (150). С. 55–61.
17. Criteria based assessment of the level of ecological safety of exploitation of electric generating power plant that consumes biofuels / Kondratenko O. et al. *2018 IEEE 3rd International International Conference on Intelligent Energy and Power Systems (IEPS–2018): Book of Papers. 10–14 September*. 2018. Pp. 57-1–57-6. DOI: 10.1109/IEPS.2018.8559570.
18. Критеріальне оцінювання рівня екологічної безпеки процесу експлуатації енергетичних установок: монографія / Вамболь С. О., Вамболь В. В., Кондратенко О. М., Міщенко І. В. Х.: НУЦЗУ, Стиль-Издат (ФОП Бровін О.В.), 2018. 320 с.
19. Аналіз оцінки соціальних втрат здоров’я населення, обумовлених забрудненням атмосферного повітря (на прикладі викидів ЗЧ10) / Турос О. І. та ін. *Гігієна населених місць*. 2012. Вип. 59. С. 52–57.
20. План дій щодо зменшення промислового забруднення повітря у містах України. Огляд варіантів політики та рекомендацій. URL: cleanair.org.ua-o-chyste-povitrya-dlya-ukrayiny-2020.pdf (access date: 15.09.2023).
21. Particulate Matter (PM) Pollution. United States Environmental Protection Agency. URL: https://www.epa.gov/pm-pollution/particulate-matter-pm basics#:~:text=PM%20stands%20for%20particulate%20matter,seen%20with%20the%20naked%20eye (access date: 15.09.2023).
22. Ambient air quality and cleaner air for Europe: Directive of the European Parliament and of the Council of 21 May 2008. URL: https://eur-lex.europa.eu/EN/legal-content/summary/cleaner-air-for-europe.html#:~:text=Directive%202008%2F50%2FEC%20of,and%20cleaner%20air%20for%20Europe.&text=WHAT%20DOES%20THE%20DIRECTIVE%20DO,environmental%20quality%20up%20to%202020. (access date: 15.09.2023).
23. Ambient air pollution: a global assessment of exposure and burden of disease / director of Public Health, Environmental and Social Determinants of Health. URL: https://apps.who.int/iris/bitstream/handle/10665/250141/9789241511353-eng.pdf (дата звернення: 15.09.2023).
24. Турос О. І., Маремуха Т. П., Кобзаренко І. В. Забруднення атмосферного повітря зваженими частинками пилу (ЗЧ10 та ЗЧ2,5) у Деснянському районі м. Києва. *Гігієна населених місць*. 2017. Вип. 67. С. 32-33.
25. Assessment of the health impacts of exposure to PM2,5 at a European level. ETC/ACC Technical Paper 2009. URL: https://acm.eionet.europa.eu/d ocs/ETCACC_TP_2009_ (дата звернення: 15.09.2023).
26. Scientific and practical problems of application of ecological safety management systems in technics and technologies: Monograph / Vambol S. O.et al. Opole: Publ. Academy of Management and Administration, 2017. 205 p.
27. Про Основні засади (стратегію) державної екологічної політики України на період до 2030 року. Закон України №2697-VIII від 28.02.2019. URL: https://ips.ligazakon.net/document/T192697 (дата звернення: 15.09.2023).
28. Деякі питання здійснення державного моніторингу в галузі охорони атмосферного повітря. Постанова Кабінету Міністрів України № 827 від 14.08.2019. URL: https://zakon.rada.gov.ua/laws/show/827-2019-%D0%BF#Text (дата звернення: 15.09.2023).
29. Вимірювання пилових частинок URL: https://www.gastech.com.ua/vymiryuvannya-palevyh-chastynok/ (дата звернення: 15.09.2023).
30. Гічов Ю. О. Очищення газів. Частина 1: Конспект лекцій. Дніпропетровськ: НМетАУ, 2015. 51 с. URL: https://nmetau.edu.ua/file/21._gichov_yu.o._ochischennya_gaziv._chastina_i.pdf (дата звернення: 15.09.2023).
31. Ручний відбір проб. World Health Organization, 2020. URL: https://www.euro.who.int/__data/assets/pdf_file/0020/130763/E88565R.pdf (дата звернення: 15.09.2023).
32. Голінько В. І., Шибка М. В. Методичні вказівки до лабораторної роботи «Вивчення методів і засобів контролю запиленості повітря» з дисципліни «Основи охорони праці» для студентів усіх спеціальностей. Д.: Державний ВНЗ «Національний гірничий університет», 2013. 16 с. URL: https://aop.nmu.org.ua/ ua/metodicki/bakalavr/oop/lp/%D0%9F%D1%8B%D0%BB%D1%8C.pdf (дата звернення: 15.09.2023).

33. П'єзобалансний вимірювач масової концентрації пилу KANOMAX 3521 / 3522. URL: https://eco-intech.com/product/pezobalansnyy-izmeritel-massovoy-kontsentratsii-respirabelnoy-pyli-kanomax-3521-3522/ (дата звернення: 15.09.2023).

34. Автоматизований пристрій контролю якості повітря НС / Грига В. М., Гуменицький М. Б., Сачовський А. М., Рудик Р. Д. ДВНЗ "Прикарпатський національний університет ім. В. Стефаника", Івано-Франківськ, Україна. URL: https://kkite.pnu.edu.ua/wp-content/uploads/sites/50/2020/05/ATSU2020_T1_P104.pdf (дата звернення: 15.09.2023).

35. Управління якістю атмосферного повітря в країнах Європи. Ecoaction, 2022. URL: https://ecoaction.org.ua/upravlinnia-iakistiu-atm-povitria-u-evropi.html (дата звернення: 15.09.2023).

36. Мобільні стандарти. Цікаво знати. URL: https://elmir.ua/articles/mobil_nye_standarty_eto_interesn.html (дата звернення: 15.09.2023).

37. Офіційна сторінка компанії «Позітрон GMBH». URL: http://www.positron.dp.ua/ (дата звернення: 15.09.2023).

38. Про затвердження форми Програми державного моніторингу у галузі охорони атмосферного повітря. Наказ Міністерства захисту довкілля та природних ресурсів України № 147 від 25.02.2021. URL: https://ips.ligazakon.net/document/RE36165 (дата звернення: 15.09.2023).