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INFORMATION AND LASER SYSTEM FOR ASSESSING HARMFUL MAN-MADE EMISSIONS

At the current stage of development in the energy, chemical, mechanical engineering, and printing industries, there is extensive use of environmentally hazardous resources such as coal, oil, natural gas, paints and coatings, and polymer materials. The high production intensity driven by market demands leads to increased consumption of energy and raw materials, which in turn causes a rise in concentrations of dust, toxic gases, and harmful liquid emissions into the atmosphere and water systems. This contributes to growing environmental pollution, the real-time assessment of which is often impeded by the limitations of conventional data collection methods.

In response, new approaches have been substantiated for the development of sensors capable of measuring levels of air contamination, particularly dust and toxic substances. These innovations are based on novel physical principles, enabling the creation of laser-based pollution concentrators, sensors utilizing the optogalvanic effect, and integrated systems that combine ion-selective sensors (such as OCM 5M) with measurement platforms. Such technologies enhance the overall effectiveness of environmental monitoring and safety systems.

A comprehensive solution to this issue involves the establishment of global environmental monitoring networks that rely on information and intelligent technologies, as well as the development of next-generation sensor models. Environmental monitoring has remained a critical issue for over a century, as industrial progress — from railroads and textile production to thermal power and petrochemical complexes — has brought not only prosperity but also significant environmental degradation. The impact has been especially pronounced with the advancement of nuclear energy and jet aviation, and further intensified by the consequences of the First and Second World Wars. More recently, the war in Ukraine has introduced a unique set of ecological threats, including explosions, damage to energy infrastructure, and the destruction of oil terminals.

Key words: ecosystem, pollution, dust pipeline, information technology, coal, laser, environmental safety, sensors.

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ІНФОРМАЦІЙНО-ЛАЗЕРНА СИСТЕМА ДЛЯ ОЦІНКИ ШКІДЛИВИХ ТЕХНОГЕННИХ ВИКИДІВ

На сучасному етапі розвитку електроенергетики, хімічної, машинобудівної та поліграфічної галузей спостерігається широке використання ресурсів, що мають підвищену екологічну небезпеку — таких як вугілля, нафта, природний газ, лакофарбові речовини та полімерні матеріали. Висока інтенсивність виробничих процесів, зумовлена ринковими вимогами, призводить до значного зростання споживання енергетичних і матеріальних ресурсів. Це, своєю чергою, викликає збільшення концентрації пилу, токсичних газів і шкідливих рідин у повітрі та водному середовищі, що призводить до зростання рівня забруднення довкілля. Через складність оперативного збору екологічних даних із використанням традиційних засобів моніторингу, оцінити реальний стан навколишнього середовища стає дедалі складніше.

У цьому контексті обґрунтовано підходи до створення сенсорних пристроїв, призначених для вимірювання рівнів забруднення повітря і — зокрема, концентрацій пилу та токсичних речовин. Розробки ґрунтуються на застосуванні нових фізичних принципів, що дозволило сконструювати лазерні концентратори забруднень, сенсори на основі оптогальванічного ефекту, а також системи, що поєднують іоноселективні сенсори типу ОСМ 5М з вимірювальними комплексами. Такі рішення сприяють підвищенню ефективності екологічного моніторингу та безпеки.

Комплексне вирішення цієї проблеми передбачає створення глобальних систем екологічного моніторингу з використанням інформаційно-інтелектуальних технологій і впровадження новітніх сенсорних рішень. Питання екологічної безпеки залишається актуальним понад століття, оскільки технічний прогрес — від залізниць і текстильної промисловості до теплової енергетики та нафтохімії — супроводжується масштабним техногенним навантаженням. Особливо суттєво зросло забруднення довкілля внаслідок розвитку атомної енергетики, реактивної авіації, а також через наслідки Першої і Другої світових воєн. Останнім часом ситуацію ще більше ускладнила війна в Україні, яка спричинила додаткові екологічні загрози внаслідок вибухів, руйнування енергетичних об'єктів і знищення нафтотерміналів.

Ключові слова: екосистема, забруднення, пилепровід, інформаційні технології, вугілля, лазер, екологічна безпека, давачі.

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Introduction

The solution to the problem of developing information technology to create environmental monitoring systems for the technological environment that would ensure high productivity and minimize harmful emissions is based on modern system and information technologies, and the development of new types of sensors for information and measurement systems. Processing of technological data, which is the basis for decision-making, and selection of additional data, which should be supplemented by data involving expert knowledge in the management process. Thus, under the influence of disturbing factors, new approaches to the development of sensors for real-time information and measurement systems, ways of displaying data flows, and interpreting their information content are required to solve control problems [1, 2, 5].

The problem of developing information technologies for the creation of environmental monitoring systems based on the use of laser information and measurement systems and sensors for remote monitoring of the concentration of harmful emissions into the environment by man-made production structures has not been fully resolved, and therefore the development of scientific principles for the creation of laser sensors for environmental monitoring with appropriate information support for the selection of heterogeneous data on the state of the object, processing and interpretation by operational personnel, their ability to assess situational risks when formulating and adopting effective management and targeted coordinating decisions is an urgent problem.

The aim of the study is to develop information technologies for creating systems for environmental monitoring of the technogenic environment of energy-intensive facilities with harmful product emissions using laser sensors, which would ensure effective control of the ecosystem and reduce the risks of emergencies in the regions.

The object of research is the processes of data acquisition from laser sensors, their processing and evaluation, interpretation, classification necessary for decision-making in environmental monitoring information systems.

The subject of the study is methods, models, information technologies for selecting and processing data streams obtained by laser sensing to assess the environmental situation of the level of environmental pollution by man-made systems.

Research methods. Taking into account the specifics of the energy activity of objects with an aggregated hierarchical structure and the difficulties in selecting, evaluating and interpreting data on their condition, the research methods are

- methods of system analysis of expert assessment of situations and environmental conditions of thermal power plants for analyzing and processing data for decision-making;
- the method of laser sensing of the environment for the selection and processing of non-standard data on the level of concentration of harmful emissions into the ecosystem, which is necessary for building the structure and means of sensors for selecting data streams for monitoring;
- methods of the theory of remote laser sensing of an object for the construction of photometers and information and measuring systems with laser sensors, which is the basis for selecting data on the concentration of dust in the atmosphere and impurities in process and water solutions as the basis for assessing the level of environmental pollution around the thermal power plants;

The scientific novelty of the research results is the developed concept based on new information and system technologies and laser remote sensing, the method of integrated use of physical, chemical and optical effects for the development of new type sensors, their information and metrological structure, synthesis methods and methods of experimental and scientific research are substantiated.

Practical significance of the research results - the results of the work and analysis of global trends in the field of thermal energy, the implemented laser concentrator at Burshtyn TPP is the only project implemented in the world practice of monitoring the combustion of high-temperature fuels. Ion-selective sensors are widely used in analytical instruments and monitoring systems that are mass-produced in Ukraine and worldwide. The optical-galvanic sensors concept proposed by the authors is used to control the concentration of the water environment based on analytical experiments in the laboratory and in the reservoir of Burshtyn TPP.

Analysis of literature sources

Analysis of the process of sensing environmental pollution by harmful emissions from man-made systems

To estimate the concentration level, the spatial and energy structure of laser signals is chosen taking into account geometric transformations so that the conditions of active sensing are met both in the allocated volume and in optical cuvettes [3, 4, 9]:

$$\vec{Z}_C\left(B_F|\alpha_C\right)=\vec{Z}_C\left(B_L|P\right)\otimes\vec{n}_S \ , \quad \left(<\alpha_S=<\alpha_C\right) \tag{1}$$

a vector component that determines the projection transformations of a laser beam with a diameter d_L. That is, according to the structure of the laser beam and the type of control method, a laser sensing signal with power $(\mathrm{PL/мL/})$ in the appropriate basis is generated:

$$\forall Z_X^C \in V_X\left(d_L \neq 0\right), P_{BL}^r Z_X^C\left(\frac{\vec{n}_S}{\alpha_S}\right)V_F\left(B_F\right)/S_F >> S_{\Pi L} \tag{2}$$

where Z_X^C - spatial component of the probing beam; $V_X\left(d_L \neq 0\right)$- beam cross-sectional surface:

$P_{BL}^r Z_X^C$ - projection of each beam point, due to interaction with the location zone with an indirect vector $\vec{n}_S$; on the photodetector area of the matrix $S_F\left(<\alpha_S,<\alpha_C\right)$, the angles of the probing and reflected beams.

For the energy structure of the beam, which contains information about the parameters of the technological environment, we have the following relations

$$\mathrm{I}_S\left(\alpha_l(\theta)\cdot l\right)_{BF}=\mathrm{I}_{0Bc}\left(<\alpha_{C,}\right)\times\alpha_l\left(\theta|<\alpha_{S,}l\right) \tag{3}$$

where: $I_0()$ - is the intensity of the probing signal; $_l()$ - is the scattering coefficient of the laser beam, which reflects the interaction of the beams with the medium of the maintenance object TO, which is characterized by the parameter.

According to the Bouguer's law, the power of the reflected laser beam at P_{0L} is the laser power: $P_S(\theta) = P_{0L} e(-\alpha_T(\theta)l)$, where $\alpha_T(\theta)$ is the scattering coefficient in the location area with the interaction trajectory l of the laser beam and the technological object; PS is the received signal power.

The measurement information is obtained based on converting the laser signal that passes through the sample medium and loses power due to photon scattering in the volume of the substance:

$$[\alpha_T(\theta)l] = \left[\ln P_{0L} - \ln P_S^*\right] \quad P_S^* = \left(P_S + \sum_{i=1}^{n} P_{Si}\right) \tag{4}$$

then the estimation of the laser beam parameter at the cuvette outlet is related to the level of the scattering coefficient in the medium and the power at the outlet of the cuvette with the sample:

$$\hat{\theta}_S /_{SL} = \varphi\left(\alpha_T \hat{(\theta)} l\right)_{SL} = \hat{\theta}_e^*\left(P_S^* /_{0L} \hat{=} const\right)_{SL} = K_Z \cdot \hat{P}_S^* /_{SL} \tag{5}$$

where: SL - logarithmic scale; $\hat{\theta}_S\big|_{SL}$ - estimation of the state parameter of the technological object; K_Z - coefficient of the sensing transformation, PS - illumination from external sources; P_{0L} - laser signal power; P_S^* - reflected laser signal - parameter carrier □.

Depending on the adopted method, a scheme for active sensing of the environmental parameter of a technological object has been developed (Fig. 1). This structure can implement two modes of active sensing:

- with modulation to increase sensitivity and expand the scale - SL;
- without modulation, which increases the influence of external illumination - PS.

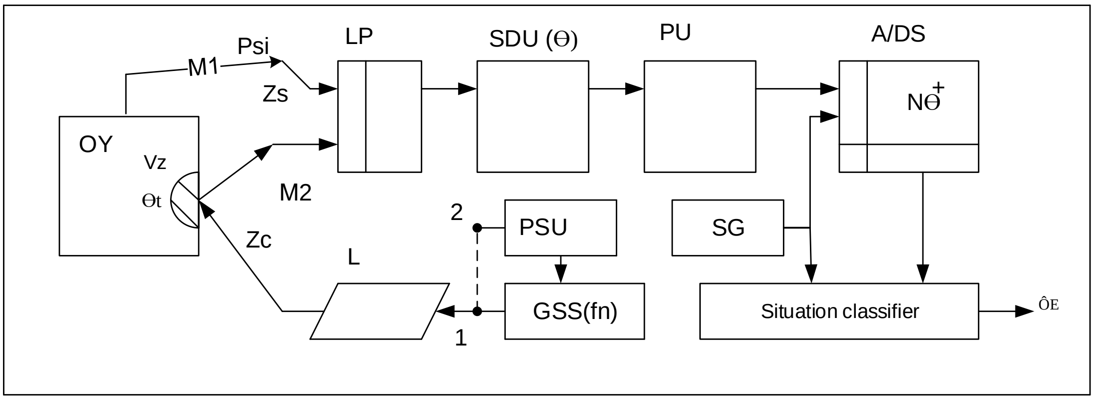

Fig. 1. Schematic diagram with active sensing of the state parameter of the technological medium by a laser

For active sensing of the process medium state parameter, the following notation is used: GSS - generator of the sensed signal; Zs - signal from the laser L; Zs - signal reflected from the zone of active interaction; LP - laser signal photodetector; SDU (θ) - signal detection unit for the state parameter (θ); PU - processing unit; SG - scale generator; A/DC - analog discrete signal converter into digital form N_θ^t - at a time t; $\hat{\theta}_E$ - expert assessment of the situation.

Estimation of the concentration level in the field of technological process sensing is based on information transformations by (Ck, θ) (according to the type of sensing method, M_1 - medium or M_2 - by the reflected beam:

$$C_K \begin{array}{l} \leftarrow Z_C(\omega_M, P_L), t \\ \rightarrow Z_S(\omega_M, P_S(C_K, \alpha_S), t) \rightarrow U_{F\Pi}(\omega_M, t, \theta_F(C_K)) \rightarrow \left|\dfrac{\hat{U}_{F\Pi}}{\theta_F(C_K)}\right| \rightarrow \hat{C}_k \end{array} \tag{6}$$

where: C_K - level of concentration of components; Z_C, Z_S - sensing modulating laser signal and reflected signal; w – modulation frequency of the laser signal.

Probing of an eco-manmade liquid medium in a sample with a laser beam to assess the concentration of pollution

To monitor liquid media, specialized transducers are needed [10], in which the process of measuring state parameters is based on a combination of methods and means of data collection to identify information features [6, 7, 8]. Standardized evaluation methods must be used in such data collection procedures:

- basic units: L - length, M - mass; T - time; I - current; □ - thermodynamic temperature, I - light intensity; N - mole of substance;

- derivatives: (ν, F)- frequency of electric current oscillations; Q - electric charge, (V, φ, E)- electric potential, potential difference, electromotive force, P - electric power, (S, Q, P)- total, active and reactive power, W - active electric energy;

- parameters of electrical components of systems: (C, LM)- capacitance, inductance, mutual inductance of elements, (R, g) - resistance to conductivity of elements and physical and chemical components of the environment.

State and secondary standards stored at the National Research Center "Institute of Metrology" (Kharkiv) are used to test measuring transducers, but there are no developed standards for evaluating physicochemical elements in solutions and measuring their concentration, which requires the development of indirect measurement methods, their hardware (sensors) and metrological support, and the selection of appropriate base measures and scales for graduation in accordance with the SI standard. At the same time, to increase the information efficiency of the data, it is possible to combine electrical, laser, and galvanic methods of controlling the process medium, which makes it possible to select data qualitatively in accordance with the algorithm of information transformations of the medium parameters by laser sensing.

The value of impurity concentration during direct sensing of a cuvette with harmful components is determined according to the method of information transformations of the laser signal power and its energy interaction with the sample medium:

$$\hat{C}_K = K_n \hat{I}(C_K, E_{l1}, E_{l2}, \theta)_{SC} \; S_C = \left\{ S_{Ci} \Big|_{i=0}^{m} \right\} \tag{7}$$

where: $\hat{C}_K$ - concentration estimate; □ - environmental parameter; S_C - concentration scale of a certain substance formed by graduating the C_{Ki} level depending on the type of components in the solution in the range of values for each chemical composition of the substance.

The concentration level assessment is formed according to the interval scale in the form

$$|Shc| \mapsto I(C_K) = \left[C_K^{/} = \min, C_K^2 = \max \middle| \theta_r \right], \tag{8}$$

for each type of measurement method.

A stand for setting up experimental studies

Let us consider the structural diagram of the stand for a comprehensive study of methods for measuring the concentration of impurities in solutions based on the use of laser sensing and galvanic potential generation (Zn/Cu) - electrodes according to the information diagram - model of interaction of the components of the medium:

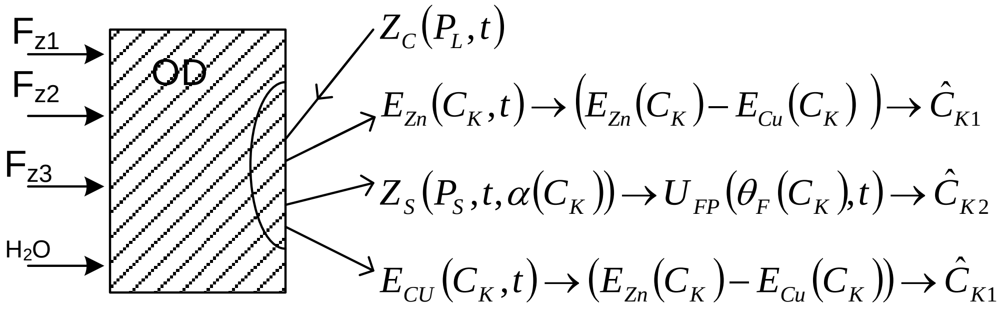

Fig. 2 Diagram of a comprehensive study of the concentration of impurities in solutions

Designation on the diagram:

(F_{Z1}, F_{Z2}, F_{Z3}) - impurities in water sample solutions from technological facilities;

C_K - concentration of impurities at the time of measurement $(t_i \in \tau_j)$, τ_j - measurement duration;

$Z_C(P_L, t)$ - probing signal of the laser with power P_{LS};

$Z_S(P_S, t, \alpha(C_K))$ - laser signal at the outlet of the cuvette with a sample of impurities in the liquid concentration C_K;

$\{E_{\mathrm{Zn}}, E_{Cu}(C_K)\}$ - electrochemical potential at the output of galvanic-optical sensors.

To control the concentration of dust and solid impurities in pollution emissions, a method of laser sensing and evaluation of the laser signal $\{C_K\}$ that has passed the basic metrological distance of the sensing structure has been developed.

$$K_i(C_K) \to \otimes \begin{matrix} \leftarrow \Pi\mathrm{sen}\left(\mathrm{R}^3/(K \to l)\right) \\ \to U\left(K_i, t, T^0C, P/C_K\right) \end{matrix} \tag{9}$$

Accordingly, a component sensor was developed, the block diagram of which is shown in Fig. 3.

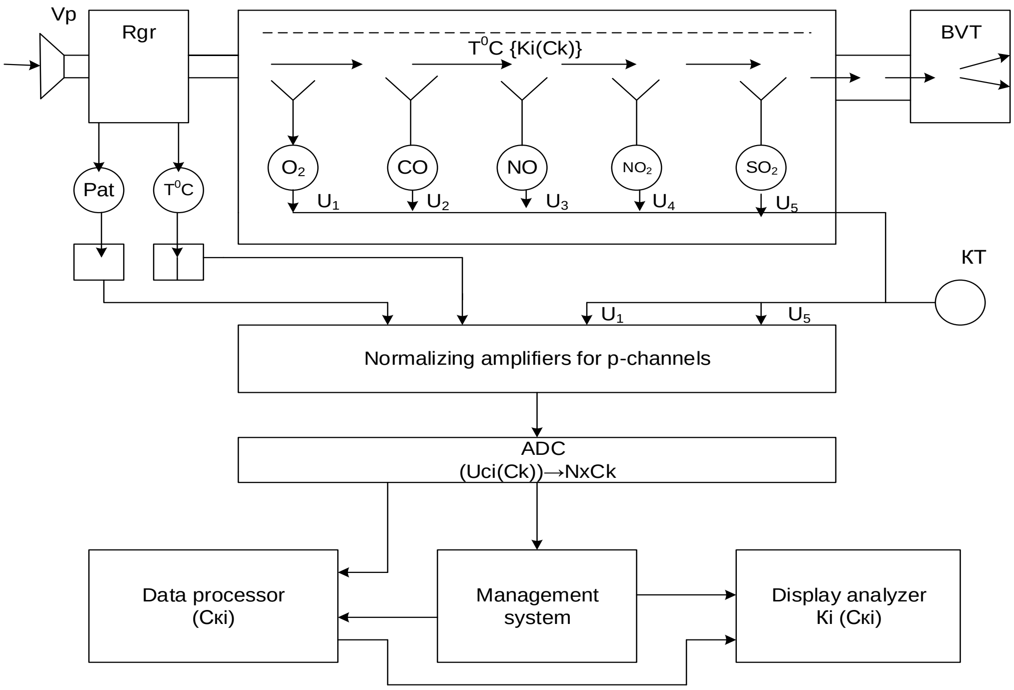

Fig. 3. Block diagram of a component sensor

Analysis of the research results

The research work carried out over the past fifteen years within the framework of the scientific and technical programs of the Center for Strategic Studies "Eco-bio-technical systems" performed both in the laboratory of laser sensing and at strategic level enterprises (Burshtyn TPP, Dobrotvir TPP, glassworks of the construction sector Bucha, Irpin, Kostopil, Rokytne) has shown the importance of creating integrated systems for environmental monitoring of the level of man-made pollution, both the environment and the entire ecosystem. The use of laser methods for sensing dust concentration and water pollution has shown their effectiveness and the creation of new types of sensors for information and measurement systems has led to new ideas for the development of sensors with integrated laser, optoalvanic and ion-selective research methods. Accordingly, it was necessary to monitor the state of the environment under the influence of emissions of harmful substances by man-made systems into the atmosphere, soil and water reservoirs based on the combination of the latest methods and technologies.

Control of the concentration of coal dust after grinding in the mill and feeding it into the dust ducts of the power unit's boilers is the basis for determining the level of combustion products depending on the power unit's load mode. The quality of grinding (microdispersed) depends on the type of coal supplied from different coal mines. Coal from different sources has a rock content (10-40%), which forms dust emissions as air pollutants, while a high level of rock content reduces the energy efficiency of coal. The source of energy is the combustion of coal itself and, accordingly, a stream of harmful gases is formed that are released into the atmosphere. The energy level of the combustion process depends on the concentration of coal dust, which, accordingly, provides the boiler's energy output during the combustion process. If the quality of coal changes with different deliveries, a sharp increase in the concentration of the coal component can lead to an emergency or boiler explosion. Therefore, it is necessary to monitor the concentration of coal dust in the dust ducts and signal the occurrence of emergency conditions. The results of coal dust monitoring at power units are shown in the tables below.

The laser concentrator of coal dust was developed in the laboratory of laser technologies of the Center for Strategic Research "Eco-Bio-Technical Systems" and a batch was manufactured by order of Burshtyn TPP in the coal pipelines of boilers of power units (dust temperature 300-600^{0}C). In accordance with the concept of laser method of dust concentration measurement, the methods of dust concentration calibration were developed. In accordance with the requirements of the technological control of the power units, the laboratory of instrumentation and automation regularly performs measurements of the concentration level based on the gravity model of the coal dust flow in the dust duct and submits the following protocols to the engineering department for reporting

Protocols for calculating the dust concentration at Burshtynska TPP is calculated by the formula.

$$C_k = \frac{\sum \Delta m_i}{Vt_i \times S}[g/m^3] \qquad (10)$$

where VI = 10 m/s is the dust flow rate; Δm_i is the total mass of dust; S is the area during the duration of dust collection $t_i = 10s$.

Table 1

Protocol № 1/21.09.21 Calculation of dust concentration in dust pipelines of block N 4: Dust pipeline A

№	m_{i0}	$\sum m_i$	Δm_i	l_j	d_j	S_j
1	300	450	150	230	18	2,5
2	400	520	120	230	18	2,5
3	300	420	120	230	18	2,5
4	300	360	60	200	18	2,5
5	300	420	120	200	18	2,5
6	300	480	180	190	18	2,5
			$\sum \Delta m_i$ 740,0			$\sum S_i$ 226 sm^2

$$C_k = \frac{0{,}74}{226 \bullet 10^{-4} \bullet 10 \bullet 10} = 3{,}2[g/m^3]$$

Table 2

Protocol № 1/21.09.21 Calculation of dust concentration in dust pipelines of block N 4: Dust pipeline B

№	m_{i0}	$\sum m_i$	Δm_i	l_j	d_j	S_j
1	1320	1450	130	9	2,5	22,5
2	1380	1560	230	9	2,5	22,5
3	1450	1670	220	8,5	2,5	22,5
4	1040	1290	220	9	2,5	22,5
5	1360	1480	120	9	2,5	22,5
6	1560	1610	50	9	2,5	22,5
			$\sum \Delta m_i$ 200			$\sum S_j$ 135sm^2

$$C_k = \frac{1090}{135 \bullet 10^{-4} \bullet 10 \bullet 10} = 8{,}074[g/m^3]$$

Table 3

Protocol № 2/21.09.21 Calculation of dust concentration in dust pipelines of block No. 4: Dust pipeline A

№	m_{i0}	$\sum m_i$	Δm_i	l_j	d_j	S_j
1	790	1190	400	9	2,5	22,5
2	790	1060	270	9	2,5	22,5
3	790	920	120	9	2,5	22,5
4	790	1000	250	9	2,5	22,5
	$\widehat{\Delta} = 200$mg		$\sum \Delta m_i$ 1040+ 200			$\sum S_j$ 90 sm^2

$$C_k = \frac{1240}{90 \bullet 10 \bullet 10} = 13{,}7[g/m^3]/2 = 6{,}8[g/m^3]$$

Table 4

Protocol № 2/21.09.21 Calculation of dust concentration in dust pipelines of block N 4: Dust pipeline B

№	m_{i0}	$\sum m_i$	Δm_i	l_j	d_j	S_j
1	700	1200	500	9	2,5	22,5
2	510	880	370	9	2,5	22,5
3	750	1200	550	9	2,5	22,5
4	630	1200	570	9	2,5	22,5
	$\widehat{\Delta} = 200\text{mg}$		$\sum \Delta m_i$ 1990+ 200			$\sum S_j$ 90 cm2

$$C_k = \frac{2190}{90 \bullet 10^{-4} \bullet 20 \bullet 10} = 12{,}16[g/m^3]$$

Discussion of the research results

Paper [11] considers the main elements of environmental management and provides an analysis of scientific approaches and concepts and meanings in the field of natural resource use and environmental protection. The methodology of this work is based on the analysis of regulatory documents and theoretical approaches to management activities in the field of environmental protection. The conclusions and proposals were formulated on the basis of such methods of scientific cognition as logical and semantic, comparative legal and legal analysis. This paper outlines the main emphases of the problem of coordination of actions of all participants in management activities in the field of environmental protection and natural resources management, such as illegal mining, inappropriate use of land, and inadequate manmade loads.

The manual [12] discusses aspects of the design and application of analytical instruments and systems aimed at solving environmental monitoring problems. It contains information on modern gas analytical complexes and systems for technological and environmental monitoring. In addition, the manual provides basic data on electronic components used in electronic systems for various purposes, including analytical equipment.

Article [13] describes the possibility of opening new areas of research using wireless sensor networks that provide greater spatial and temporal resolution. This allows researchers to "observe the unobservable" by collecting a variety of data (from temperature to images and sound) over large areas at high frequency, even several times per second. This opens up opportunities for intensive and widespread data collection by ecologists and field biologists, as well as for collecting new types of data. Real-time data streams allow researchers to respond quickly to events, expanding the possibilities of research in the field.

Paper [14] discusses the innovative use of advanced sensors and sensor networks in environmental research. These advanced sensors provide a new way to observe the world, which allows for a broader spatial and temporal scope of research, provides a more accurate assessment of invisible or complex phenomena, and, most importantly, they can lead to unexpected discoveries or the development of new scientific approaches.

Article [15] discusses land use variability as a key factor in determining the spatial differentiation of regional environmental risk. Landscape environmental risk assessment is used to measure and predict environmental quality. This study used quantitative analysis of land use dynamics in the Tarim River basin from 2000 to 2020 using ENVI 5.6 software and Landsat TM and ETM+ images (taken in 2000, 2010, and 2020). In addition, the level of environmental risk and its spatial and temporal features were studied using geostatistical methods based on landscape pattern indices.

Thus, based on the results of the work performed, the following scientific novelty and practical significance of the research results can be formulated.

Conclusion

The article substantiates the requirements for the information structure of the monitoring system for controlling the production process of an energy-active facility. Effective monitoring of harmful emissions of combustion products from thermal power plants is possible if a database and knowledge about the organization of production, physical and chemical energy transformations of resource components is built in the structure of state environmental monitoring. Based on the information technology of data selection, processing, evaluation, and interpretation, a decision support system has been developed to manage and coordinate technological regimes to reduce environmental pollution. The article also analyzes the current state of the problem of environmental monitoring, known means and methods of controlling the concentration of harmful emissions by technogenic systems of various companies and justifies the need to create laser sensors for data collection.

An information technology was developed to solve the problem of creating environmental monitoring systems and selecting and processing heterogeneous data on the level of pollution, which would ensure continuous monitoring of the concentration of harmful emissions from man-made production structures into the atmosphere and water in reservoirs.

An information technology for analyzing and evaluating data obtained in the process of laser sensing of the environment, which is necessary for risk assessment in decision-making in limit and emergency modes of operation of energy-active facilities with high concentrations of harmful emissions in real time, has been developed.

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