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SUBSTANTIATION OF THE ENVIRONMENTAL AND ENERGY APPROACH OF IMPROVEMENT OF TECHNOLOGICAL REGULATIONS OF WATER TREATMENT SYSTEMS

Об'єктом дослідження є екологічна безпека споруд очищення стічних вод при мінімізації ресурсовитрат на реалізацію технологічних процесів видалення забруднювачів із стоків. Існують фактори, які комплексно створюють передумови щодо неефективності діяльності із підтримання екологічної безпеки систем очищення стічних вод, а відповідно, і складності реалізації їх технічного регулювання. До таких чинників відносяться:

- відсутність у режимі реального часу повноти інформації щодо конкретного комбінованого процесу водоочищення, складність його адекватного дослідження навіть у лабораторних умовах;
- відсутність і/або низькі точність та швидкодія сучасних технічних засобів вимірювань складу водних розчинів, особливо у промислових умовах.

Усунення впливу негативних чинників досягається шляхом удосконалення науково-теоретичних засад створення технологічних регламентів споруд очищення стічних вод при підвищенні екологічної безпеки промислових об'єктів з урахуванням вимог зменшення ресурсовитрат згідно концепції синтезу систем екологічного менеджменту.

Обґрунтовано та аналітично отримано еколого-енергетичний критерій оцінки функціонування споруд очищення стічних вод. Аналіз результатів виробничого впровадження дозволив констатувати, що еколого-енергетичний критерій, який показує питомі енергозатрати для забезпечення екологічної безпеки водоочищення, прийнятно застосовувати при налаштуванні промислових систем водоочищення та створенні їх технологічних регламентів. Протягом місяця виробничих досліджень значення еколого-енергетичного критерію мали відхилення від заданого на $\pm 3,4\%$, що є технологічно прийнятним показником.

Удосконалена концепція постановки інтегрованих цілей досягнення екологічно безпечного водовідведення згідно міжнародних систем оцінки якості управління підприємствами на основі еколого-енергетичного критерію створює передумови для отримання сертифікату ISO 14001. Впровадження систем екологічного менеджменту забезпечить:

- зниження фінансових витрати за рахунок економії природних ресурсів і зменшення штрафних санкцій;
- зростання прибутку завдяки потенційній реалізації повторного використання водних ресурсів.

Ключові слова: очищення стічних вод, видалення забруднювачів, екологічно безпечне водовідведення, екологічний менеджмент.

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1. Introduction

The operation of water treatment equipment is based on the implementation of the technological regulation (TR) – a regulatory document for internal use [1, 2], relates to the technological documentation system of Unified system for technical documentation (USTD), which, in turn, is part of the Unified system for technological production preparation (USTPP) [3].

Technological regulations should facilitate the flow of processes of appropriate (planned) quality with a minimum consumption of resources. Moreover, it should contribute to the achievement of optimal technical and economic indicators of production, to regulate the conditions of production processes and operation of production as a whole [3].

The mandatory availability of such a document at wastewater treatment facilities, which includes water purification equipment, is provided for by the current Order of the State Committee of Ukraine for Housing and Communal Services No. 05 dated July 5, 1995. In the context of technical regulation of water purification systems, technological regulations are a prerequisite for the uninterrupted functioning of the complex of water purification equipment with the mandatory fulfillment of environmental safety conditions while minimizing resource costs. At the same time, there are factors at production facilities that systematically negatively affect the fulfillment of these conditions: insufficient nomenclature of measuring devices, potential effects of unpredictable factors of a natural and technogenic nature.

At the same time, insufficiently object – oriented TRs can lead to poor – quality functioning of treatment facilities and, consequently, to environmental pollution.

That is why the creation and implementation of new approaches to improve the creation and compliance with the TR of treatment facilities is relevant.

2. The object of research and its technological audit

The object of research is the environmental safety of wastewater treatment plants while minimizing resource costs for the implementation of technological processes for the removal of pollutants from effluents.

According to the Law of Ukraine «On Technical Regulations and Conformity Assessment» [4], a specific requirement of an object is a stated need or expectation fixed in technical regulations, standards, technical specifications or in another way. At the same time, the object of conformity to a specific material, product, installation, process, service, system, respectively, wastewater treatment plants (WWTP) also correspond to this definition. So, in relation to them, it is necessary to implement tests (determining the characteristics of the object of assessment) and establish an assessment of their compliance with relevant regulatory documents (the process of proving that the requirements for products, process, services, systems have been met).

Mandatory components of the TR, the requirements of which must comply with the current WWTP:

- characteristics and features of the treatment facilities;
- quality control of effluents at the entrance to the equipment and treated wastewater at the discharge;
- information about: the volume of the spillway, the consumption of electricity and other energy carriers used to ensure the stable operation of the system for removing pollutants from effluents.

At the same time, there are factors that comprehensively create the prerequisites for the inefficiency of metrological activity to ensure the uniformity of measurements of the implementation of the assessment of compliance with WWTP, and accordingly the complexity of the implementation of technical regulation [5] based on TR:

- uncontrollable and unpredictable actions of emergency situations of natural and man – made nature;
- lack of real – time information on a specific combined process of water treatment, the complexity of its adequate research, even in laboratory conditions;
- lack and/or low accuracy and speed of modern technical means of measuring the composition of aqueous solutions, especially in industrial conditions.

3. The aim and objectives of research

The aim of research is improvement of the scientific and theoretical foundations for the creation of technological regulations for wastewater treatment plants while increasing the environmental safety of industrial facilities, taking into account the requirements for reducing resource costs in accordance with the concept of implementing environmental management systems.

To achieve this aim, it is necessary to complete the following tasks:

1. Theoretically substantiate the environmental and energy criterion for water treatment.

2. Check in production the environmental and energy criterion for the functioning of wastewater treatment plants.

3. Improve the methodology for creating technological regulations for wastewater treatment plants based on environmental and energy criteria in accordance with the concept of environmental management systems (EMS).

4. Research of existing solutions of the problem

Analyzing the structure of various technological regulations, let's single out the works that are part of the structure of such regulations [6]:

- verification and adjustment of the components of the water treatment complex [7];
- diagnostics of the automation node(s);
- rapid analysis of the liquid at the inlet and outlet of the water treatment plant (or appropriate studies in the laboratory);
- diagnostics of measuring instruments for water quality and the state of technological equipment;
- regulation of pumping equipment for pressure and costs;
- diagnosis of individual functional and technological units of water treatment (filters, electrolyzers, aeration tanks, sand traps, etc.);
- final test of the complex with full control of all nodes;
- examination of adjacent nodes for integrity;
- formation of an official opinion on the status of the device.

Analyzing the composition of technological regulations and the features of the functioning of water treatment equipment, it is possible to conclude that the key and very complex tasks when fulfilling the technological regulations directly at the factory are [8]:

- control of technological processes at design – established sampling points for wastewater and sludge, characteristics of existing monitoring instruments of treatment facilities [9];
- technological analysis of the equipment according to production operational indicators, resource costs, cleaning efficiency in accordance with the established criteria and indicators [10].

Moreover, the more difficult the task of water purification, the more cumbersome and less reliable (efficient) control over compliance with regulatory requirements. For example, when implementing the technological scheme of the chemical method for removing contaminants from the international concern Siemens, it is necessary to simultaneously monitor more than 40 technological quantities (according to the manufacturer's requirements and the actual availability of a small number of reliable sensors) [11].

At the same time, effluents (domestic, industrial and atmospheric) usually contain a large number of inorganic and organic components [12], their exact composition, even in qualitative terms, can't always be predicted in advance – in the vast majority of cases this can't be done. For example, even with simple mixing of effluents from various shops of the enterprise, chemical reactions occur between the components of these effluents, leading to the formation of new pollutants.

At the same time, the development of similar European regulatory documents is more object – oriented and is based on a system of permits for discharges [13]:

- taking into account the characteristics of the best practically applicable technology (best available technology, BAT) [14];

– taking into account the need to ensure compliance with environmental quality standards (EQSs), which is part of the goal of ensuring the quality of the water intake [15].

At the same time, the classic shortcomings of the methodology for the development of TR for water treatment systems [16], concerning foreign regulatory solutions:

- development of technological regulations does not take into account the effect of emergencies of anthropogenic and natural origin on water treatment processes, only «after – action» is calculated – minimization of consequences after an accident;
- requirements of energy efficiency and financial components of the operation of water treatment plants are not comprehensively taken into account.

Moreover, in fact, there is no single algorithm for writing TR for combined WWTP, which combines various methods of influencing pollutants, which causes significant practical problems in creating effective ecological safe systems capable of working for a long time.

Summing up the above analysis of studies by other authors, it should be noted the lack of unified approaches to create technological regulations for WWTP and the fact that they do not take into account complex environmental and energy requirements. This emphasizes the prospect of a study to develop a methodology for the implementation of environmental management systems in relation to water treatment.

5. Methods of research

The methodological support for further research is based on the elimination of the identified key shortcomings of the existing TRs according to the requirements of resource conservation for WWTP (Table 1).

The rationale for the environmental and energy criterion is advisable to fulfill on the basis of the provisions of DSTU ISO 50001:2014 «Energy Management Systems»:

- paragraph 3.8: Energy efficiency – the ratio (coefficient) or other quantitative relationship between the result obtained (initial indicator), that is, between the work performed, services, goods or energy and the input indicator;
- paragraph 3.12: Energy performance – measured results on energy efficiency, energy use and energy consumption;
- paragraph 4.6.1: Organization shall ensure periodic monitoring, measurement and analysis of the key characteristics of its operations that determine energy characteristics. Key characteristics should cover at least: the essential importance of energy use and other results of energy analysis.

Therefore, taking into account experimental tests and theoretical developments [16, 17], it is necessary to develop a universal criterion for evaluating the efficiency of treatment of multicomponent wastewater, which would take into account its cost in addition to the quality of the treatment process.

When creating such a criterion, the expression for calculating the technical effectiveness of water treatment is taken as the basic one:

$$P = \frac{(C_{ent} - C_{aft})}{C_{ent}} \cdot 100\% \quad (1)$$

where C_{ent} – the concentration of pollutants entering the treatment, g/dm³; C_{aft} – concentration of pollutants after purification, g/dm³.

Table 1

Methodological foundations for improving the structural components of modern technological regulations for wastewater treatment plants

Modern TR analogues	Justified TR based on resource saving and emergency risk accounting
<i>Preamble.</i> The technological regulations should clearly illuminate in stages the entire process of removal, collection and treatment of wastewater	<i>Preamble.</i> The technological regulation should clearly illuminate in stages the entire process of removal, collection and treatment of sewage from settlements with measures at each of these stages to comply with resource conservation and counteract the risks of emergencies
Information about the parameters and quality of the spillway	Water technological passport of the enterprise indicating the sources of pollution (including technological processes) and potential risks of emergencies
Characterization and features of the sewage system	Description and features of the wastewater system with an indication at each stage of measures to comply with resource conservation and countering the risks of emergencies
Characteristics and features of the treatment facilities	Characterization and features of the operation of treatment facilities with an indication at each stage of measures to comply with resource conservation and countering the risks of emergencies, focusing on automation systems
Quality control of treated wastewater at the discharge (with what frequency and with what laboratories the control is carried out)	Quality control of treated wastewater at the discharge and at the entrance to the treatment plant (with what frequency and which laboratories are monitored). And also with the obligatory inclusion of technical and software that can control in real time: the quality of effluents at different stages of pollutant removal, the resource consumption of water treatment and sanitation
Disaster Recovery Activities	Disaster recovery and preventive emergency response measures
Conclusion on the availability of appropriate resources at the enterprise for high – quality and sustainable provision of drainage and water treatment	Conclusion on the availability of appropriate resources at the enterprise for high – quality and sustainable provision of drainage and water treatment

At the same time, energy consumption is taken as the main resource consumption, since WWTP is used by electrical technologies to implement pollutant removal processes – the energy and energy recovery of WWTP processes is more than 50 % [16].

6. Research results

6.1. Justification of the environmental and energy criterion for water treatment. To establish the electricity costs for the effective removal of the pollutant, let's calculate its ratio to the consumed capacity during the time the pollutant removal operations:

$$EF_y = \frac{\left[\left(\frac{L_{act} - MPC1}{MPC1} \cdot 100\% \right) + \dots \right] \cdot \sum_{i=1}^N Q_i}{\sum_{i=1}^N W_i} \quad \text{\% /kW}, \quad (2)$$

where L_{act} – the actual value of the corresponding indicator of wastewater quality; $MPC1, \dots, MPCN_{st}$ – standard values of the corresponding indicators of wastewater quality;

Q – equipment operating time, h; W – electricity spent on water treatment, kW year; N – the number of wastewater quality indicators, pieces.

If one installation (a complex of treatment facilities) provides the rationing of several parameters, such an environmental and energy criterion:

$$EF_y = \frac{\left[\left(\frac{L1_{act} - MPC1}{MPC1} \cdot 100\% \right) + \dots + \left(\frac{LN_{act} - MPCN}{MPCN} \cdot 100\% \right) \right] \cdot Q}{W} \quad \%/kW. \quad (3)$$

At the same time, one of the most common methods in Ukraine for assessing the quality of surface waters, including those formed by the discharge of industrial wastewater, is the method for determining the pollution multiplicity scores. For each ingredient, on the basis of actual concentrations, points of exceeding the maximum permissible concentrations (MPC) K_i and the frequency of occurrence of excess cases H_i are calculated, as well as the total estimated score of water pollution – B_i :

$$K_i = \frac{C_i}{MPC_i}, \quad (4)$$

$$H_i = \frac{R_{MPC_i}}{R_i}, \quad (5)$$

$$B_i = K_i \cdot H_i, \quad (6)$$

where C_i – concentration of the i -th ingredient in water; MPC_i – the maximum permissible concentration of the i -th ingredient; R_{MPC_i} – the number of cases of exceeding the MPC for the i -th ingredient; R_i – the total number of measurements of the i -th ingredient.

Ingredients for which the total estimated score is greater than or equal to 11 are allocated as limiting pollution indicators (LPI). By the value of the combinatorial pollution index, the class of water pollution is established. The combinatorial pollution index itself is calculated as the sum of the total rating points of all the ingredients.

Then, having received from (4) the MPC_i :

$$MPC_i = \frac{C_i}{K_i}, \quad (7)$$

substitute (7) into (3) (assuming that $C_i = LN_{act}$):

$$EF_y = \frac{\left[\left(\frac{L1_{act} - \frac{L1_{act}}{K_1}}{\frac{L1_{act}}{K_1}} \cdot 100\% \right) + \dots + \left(\frac{LN_{act} - \frac{LN_{act}}{K_N}}{\frac{LN_{act}}{K_N}} \cdot 100\% \right) \right] \cdot Q}{W}. \quad (8)$$

Hence, the relationship between the environmental indicator of the points of the multiplicity of exceeding the MPC and the environmental and energy criterion (3):

$$K_1 + \dots + K_N = \frac{EF_y \cdot W}{100\% \cdot Q} + N. \quad (9)$$

That is, an increase in the value of the environmental – energy criterion corresponds to an increase in the sum of the points of the multiplicity of exceeding the MPC.

It is also established that the overall assessment score is directly proportional to the environmental and energy criterion for water treatment technologies:

$$\frac{B_1}{H_1} + \dots + \frac{B_N}{H_N} = \frac{EF_y \cdot W}{100\% \cdot Q} + N. \quad (10)$$

At the same time, the created ecological and energy criterion allows eliminating an important drawback of exclusively environmental criteria (4)–(6) – they focus on achieving the environmental goals of water treatment without taking into account the efficiency of use of raw materials, materials and energy. Although at real facilities there is always not only the creation of an environmental hazard, but also the overexpenditure of resources for water treatment (Fig. 1).

So, it can be stated that such an ecological and energy criterion (2), which shows specific energy consumption for ensuring technical efficiency, is acceptable to apply to adjust the functional parameters of real water treatment systems to it. At the same time, imitating, if necessary, the effect of emergencies and the necessary reactions to them.

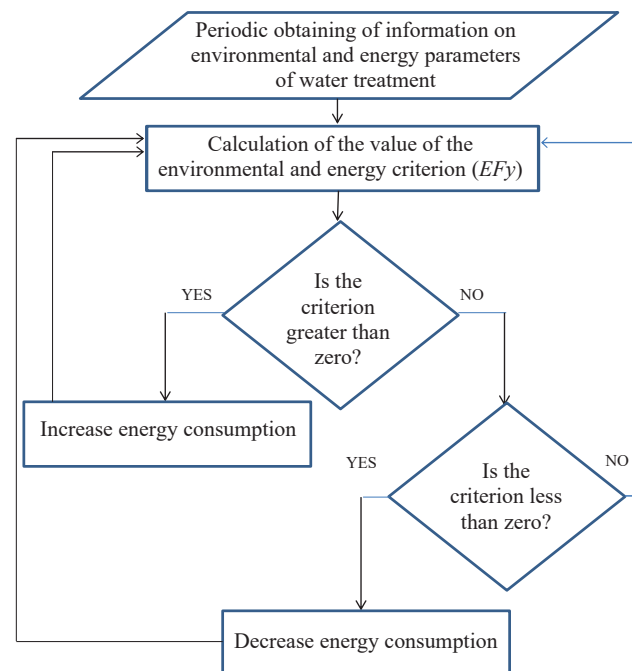


Fig. 1. The block diagram of the algorithm for the practical use of environmental and energy criteria for the treatment of industrial wastewater

6.2. Production verification of the environmental and energy criterion for the functioning of wastewater treatment plants. A production check of the environmental and energy criterion took place at a small – scale metal-lurgy enterprise, where the daily expenses of wastewater requiring treatment were $18 \text{ m}^3/\text{day}$ ($\pm 2 \text{ m}^3/\text{day}$). The technological task is the treatment of effluents from showers and the territory of the production workshop. It is established by experimental modeling that the removal

of synthetic surface – active substances (SAS) will ensure the removal of other pollutants (ammonium nitrogen, oil products, ammonium nitrogen) – the implementation of the dominant dynamic pollutant method [16].

It is determined that emergencies can be caused by unpredictable contaminants entering sewage (other situations, for example, the simultaneous use of all showers) are generally taken into account at the design stage. Such pollutants include toxic lead, which can get on workers' clothing near technological units, and then flush into the sewers.

That is why the electrotechnological system includes an electrocoagulator with a function of pH correction in alkaline solutions with the subsequent neutralization of effluents. Also integrated in WWTP: sorption filter, deaerator with electrolysis destruction, hydrodynamic intensifiers.

Setting the equipment to ensure the environmental and energy criterion (2) makes it possible to fulfill the requirements for observing the quality of water treatment while minimizing resource costs – criterion (2) should deviate from zero $\pm 3.4\%$ within a month (Fig. 2).

The results of the industrial use of improved approaches to the synthesis of technological regulations of industrial water treatment systems at a small metallurgy enterprise have allowed fulfilling environmental requirements for the quality of wastewater of enterprises. And also to introduce resource – saving measures in the operating conditions of WWTP, improving the technical regulation of the latter.

Thus, the prerequisites have been created for improving the methodology for the synthesis of TRs using the environmental and energy approach and the introduction of EMS at enterprises.

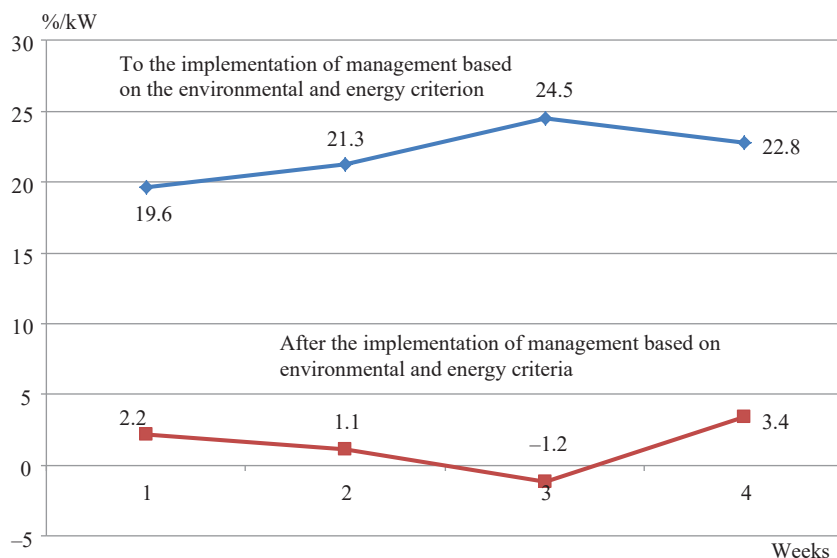


Fig. 2. Comparison of energy efficiency of electrotechnological industrial water treatment (small metallurgy enterprise)

6.3. Improving the methodology for introducing concepts of environmental management systems in relation to wastewater treatment plants based on environmental and energy criteria.

Based on the developed method for constructing technological regulations for water treatment systems, the concept of iterative integrated management of environmental water resources by enterprises on the basis of IWRM (Integrated water resources management) and an improved methodology for the WWTP TR synthesis are improved (Fig. 3).

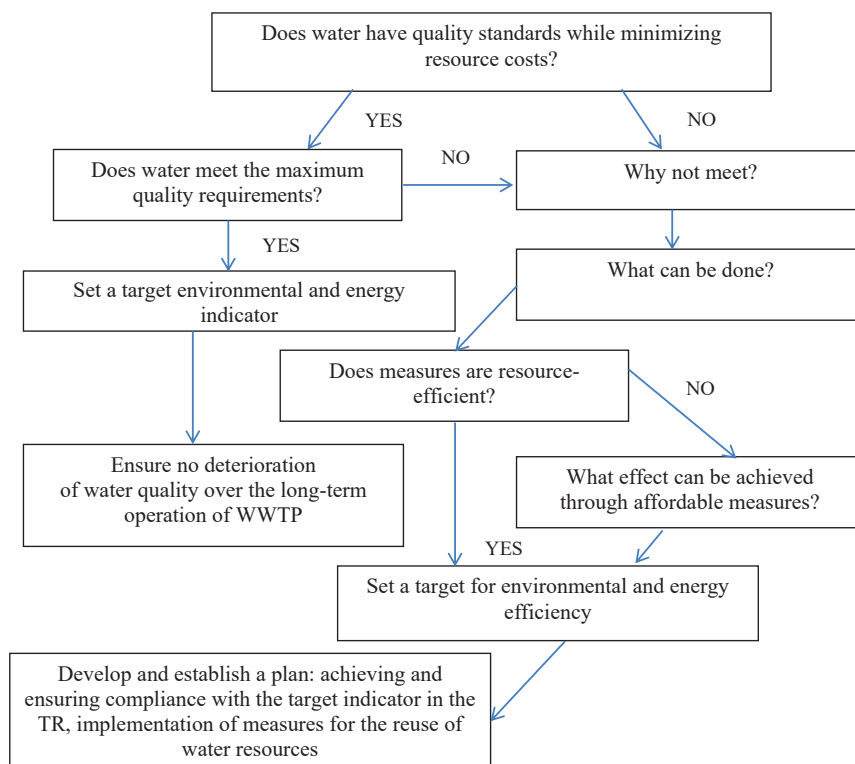


Fig. 3. An improved methodology for creating technological regulations and achieving environmentally friendly sanitation in accordance with international systems for assessing the quality of enterprise management

At the first stage of creating an EMS, it is planned to develop a sustainable development safety scheme based on an enterprise's water technological passport (WTP) with the creation of a conceptual model of water resource flows. Moreover, technological solutions for the construction of a new enterprise or the reconstruction of an old one should not cause environmental imbalance, regardless of the industry sector.

The second stage in the implementation of EMS is the testing (optimization) method of the model created at the first stage, taking into account the potential impact of anthropogenic and natural emergency situations:

- separate models of EMS elements are studied (based on conceptual decomposition), where specified (target) parameters are fixed;

– simulation of resource saving of technological parameters of the operation of the equipment for transportation and water treatment (including the use of quasi – physical physical models, virtual measures, etc.) takes place.

The third stage of the implementation of EMS is pre – design, when a business plan is compiled on the basis of the data obtained, with a mandatory comprehensive assessment of both economic (for example, through a profitability index) and technological (energy efficiency) criteria for project prospects.

At the same time, the use of new and improved scientific and theoretical foundations of the regulatory framework of industrial water supply systems makes it possible to implement the concept of integrated goals for achieving resource – efficient water supply in accordance with international systems for assessing the quality of enterprise management, taking into account environmental and energy efficiency requirements.

7. SWOT analysis of research results

Strengths. A key advantage over analogues is the unified methodological support for the creation of object – oriented technological regulations of WWTP, which ensures that environmental safety requirements are minimized and resource costs are minimized.

Weaknesses. The weaknesses of the proposed approaches include:

- need for preliminary laboratory and experimental studies;
- lack of complex mathematical and software modeling of water treatment processes.

Opportunities. The prospect for the development of an environmental and energy approach is the synthesis of mathematical and software that would allow to quickly diagnose and predict the environmental safety and resource costs of specific WWTPs based on the enterprise's data on the quality of effluents. This would allow an estimated saving of about 20 % of the financial costs of using existing equipment.

Threats. The threat to the implementation of the proposed solution lies in the lack of the necessary range of reliable sensing elements that can work in real time (clearly less than 30 % of the needs). This at certain facilities may make it impossible to quickly calculate the environmental and energy parameters of WWTP.

8. Conclusions

1. The justified environmental and energy criterion allows to eliminate an important drawback of exclusively environmental criteria for the effectiveness of water treatment, since the latter are oriented only toward achieving the environmental goals of water treatment without taking into account the efficiency of use of raw materials, materials and energy. The proposed criterion is aimed at the integrated creation of environmental safety of WWTP and the elimination of resource overruns in water treatment.

2. An analysis of the results of industrial implementation has allows to state that the created environmental and energy approach is acceptable to use when setting the parameters of industrial water treatment systems and creating their technological regulations. At the same time, within a month the value of the environmental and energy

criterion was at a technologically acceptable level – they had deviations from zero ± 3.4 %.

3. An improved concept for setting integrated goals to achieve environmentally friendly sanitation in accordance with international systems for assessing the quality of enterprise management on the basis of the environmental and energy criterion creates the prerequisites for:

- obtaining ISO 14001 certificate (ensuring compliance with the relevant requirements throughout the entire life cycle of WWTP);
- reduction of financial costs by saving resources and reducing penalties;
- profit growth due to potential implementation of water reuse schemes.

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DEVELOPMENT OF NATURAL UNDERGROUND ORE MINING TECHNOLOGIES IN ENERGY DISTRIBUTED MASSIFS

Об'єктом дослідження є технологія і технічні засоби для підземного видобутку руд в енергонарушених масивах. Одним із найбільш проблемних місць є утворення техногенних порожнеч, які впливають на виникнення і перерозподіл напружено-деформаційного стану (НДС) масиву гірських порід. Їх існування в земній корі провокує вплив геомеханічних і сейсмічних явищ, аж до рівня землетрусів.

В ході дослідження використовувалися:

– дані літературних джерел і патентної документації в області технологій і технічних засобів для підземного видобутку руд в енергонарушених масивах, обґрунтування технологічних параметрів експлуатаційних блоків;

– лабораторні та виробничі експерименти;

– фізичне моделювання і підбір складів твердіючих сумішей.

Виконано аналітичні дослідження, порівняльний аналіз теоретичних і практичних результатів за стандартними і новими методиками за участю авторів.

Розглянуто питання сейсмогеодинамічного моніторингу НДС масиву гірських порід при безпечній розробці рудних родовищ скельного типу. Показано взаємодію природних і техногенних систем, що забезпечують геомеханічну збалансованість рудовміщуючих масивів. Досліджено можливості управління геомеханіки масиву із заповненням техногенних порожнеч різноміцними сумішами і хвостами підземного вилуговування металів із некондиційних руд. Дана типізація процесів і сформульовані відмінні ознаки підземного блокового вилуговування металів із скельних руд в аспекті управління геодинамікою масиву. Показана принципова оцінка комбінованих технологій із раціоналізацією використання НДС гірського масиву для регулювання знаку і величини напружень в природних і штучних умовах. Зроблено висновки щодо ефективності керованої взаємодії природних і техногенних систем, що забезпечують геомеханічну збалансованість масивів і земної поверхні в районі освоєння надр протягом довгого періоду часу. Результати досліджень можуть бути використані при підземній розробці рудних родовищ складної структури України, Російської Федерації, Республіки Казахстан та інших розвинених гірничодобувних країн світу.

Ключові слова: напружено-деформаційний стан, гірський масив, підземна розробка, природоохоронна технологія, геомеханічна збалансованість.

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1. Introduction

In the case of man-made intervention in the subsoil, the interaction of natural and technical systems that en-

sure the geomechanical balance of the masses in the area of subsoil development becomes a general issue in the development of ore deposits. At the same time, it should be possible to monitor the stress-strain state (SSS) of the