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DEFINITION OF ENVIRONMENTAL RISK AS INTEGRAL CRITERION IN ASSESSING OF MAN-CAUSED LOAD

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У статті представлено розроблені залежності визначення екологічного ризику як інтегрального критерію у разі оцінювання техногенного навантаження промислового об'єкту на стадії проектування. Розрахунок екологічного ризику запропоновано здійснювати на основі методу «індекс-ризик» із використанням запропонованих екологічних індексів проектованих промислових об'єктів. Розроблену методику апробовано на проекті реконструкції Миронівської теплоелектростанції (Україна). Рівень техногенного навантаження встановлено неприйнятним

Ключові слова: проектований промисловий об'єкт, техногенне навантаження, індекс, екологічний ризик, інтегральний критерій

В статье представлены разработанные зависимости определения экологического риска как интегрального критерия при оценивании техногенной нагрузки промышленного объекта на стадии проектирования. Расчет экологического риска предложено осуществлять на основе метода «индекс-риск» с использованием предложенных экологических индексов проектируемых промышленных объектов. Разработанная методика апробирована на проекте реконструкции Мироновской теплоэлектростанции (Украина). Уровень техногенной нагрузки установлен неприемлемым

Ключевые слова: проектируемый объект, техногенная нагрузка, индекс, экологический риск

1. Introduction

Environmental pollution by chemical, metallurgic and mining industries, nuclear and thermal power plants, sugar plants, road, and drainage systems causes by human impacts on the ecosystem of Ukraine. Industry influences the ecosystem primarily through their direct destruction, particularly mining and resulting emissions in the atmosphere and hydrosphere pollutants that are carried through the atmosphere over long distances and penetrate almost all landscapes. The main objective in term is to minimize the increase of anthropogenic impacts on the environment. Therefore, development of approach to the assessment of man-caused load from the introduction of the ecological system designed industrial facilities are an important area of research.

2. Analysis of literature data and problem statement

The object of the research is to evaluate the impacts of projected industrial objects on the industrial ecological system with the aim of determining the man-caused load. The main objective of the assessment of projected man-caused load of industrial plants is the accumulation, systematization and analyzing information on the quantitative relationship between the industrial object and the environment to obtain the following results: assessment of the components of the environment and to identify the causes of negative disturbances in the environment, establishing sources and factors of negative external effects (in this case – industrial facilities); forecasting the general admissibility changing load for the environment, the establishment of the most dangerous impacts and comparison of the contribution of various types of impacts. To assess the contribution of various factors influencing the environment regulatory methods are used at the design stage of an industrial facility a method of comparing the obtained quantitative estimates of the approved standards (method of assessment of the environmental impact assessment is used (EIA) [1]).

Today risk assessment is a mandatory procedure in EIA at a design stage [1]. According to the publication [2], the risk is considered as the probability of adverse effects on the health of the population, does not include impacts from industrial projects at the design stage, mathematical dependence of the risk assessment not proposed. This publication [3] the authors propose to use integrated environmental indices when evaluating anthropogenic impact on the atmosphere, surface water, soil, can be used in EIA, but the mathematical dependences do not offer. In the publication [4] propose methods for assessment of the environmental safety of using indexes and risk assessment, quantitative procedure for determining these estimates are not offered. In the publication [5] researched the main causes which create risks and affect the environmental safety. The authors of [6] conducted a review of threats to human health risk assessment offer to conduct in view of the dangers and effects on the human body, the stage of designing the object does not include. The authors of [7] propose to use a probabilistic approach to environmental risk assessment using probabilistic models. This approach can not be applied at the stage of design objects; this is due to the insufficient information about the parameters of the distribution function of random variables and incomplete statistics about equipment failures and the emergence of various adverse events.

For practical assessment of man-caused load on the design stage it is necessary to build an integrated test (formal parameter), which summarizes the broader group of indicators and allows to quantify the effects of the investigated object in the design phase and subsequently decide on the acceptability of implementing such a facility in the industrial ecosystem. Therefore, developing dependency assessment of environmental risk as an integral criterion using the index from the impacts of projected industrial facilities that could be used for EIA is important direction of research.

3. Development an approach to the assessment of man-caused load using the environmental risk as an integral criterion

To calculate the environmental risk assessment as an integral criterion for assessment of man-caused load must consider the impact that the industrial facility has on the ecosystem at the design stage. In conditions of insufficient output information at the design stage developed by the authors suggest to use index estimates calculated using the desirability Harington function based on normative indicators incorporated in the EIA method [8, 9].

In general terms, the unified index evaluation of the impact has the following form (1) [8, 9]:

$$I_i = 1 - d_i = 1 - e^{-(e^{-y_i'})}, \qquad (1)$$

where I_i – index assessing of the i type level the impact of an industrial facility on the environment, dimensionless; d_i – function of desirability of i industrial facility effects on the components of the environment , dimensionless; e – exponent; y_i' – quantitative indicators that takes into account features of industrial facility in terms of i type of impacts (chemical, physical) on the components of the environment, which is associated with the quantitative indicators $П_i$ (is defined according to the norms of Ukraine) and the maximum values of $П_{max}$ (acceptable limit value impact on the environment) and minimum $П_{min}$ (unacceptable impact limit value on the environment) values of the entire set of specific pollutants and is given by (2):

$$y_i = (2 \cdot I_i - (I_{max} + I_{min})) / (I_{max} - I_{min}). \qquad (2)$$

Thus, the formula (2) calculates the specific object value y_i'.

For the purpose of calculating the man-caused load on the environmental system assessment indexes of chemical and physical effects of the projected industrial facility to the environment were developed (Table 1, 2) [8, 9].

Table 1

Indexes assessment of chemical impacts of projected industrial facilities

The component of the environment	The mathematical formula for calculating the index	Symbols
Atmosphere (i=1)	$I_i = 1 - e^{-(e^{0.25 \cdot КП - 1})}$	КП – the rate of excess standard pollution, nondimensional
Water (i=2)	$I_i = 1 - e^{-(e^{0.33 \cdot I_E - 1.33})}$	I_E – integrated environmental index of water, nondimensional
Soils (i=3)	$I_i = 1 - e^{-(e^{0.016 \cdot Zc - 1})}$	Zc – total pollution index of soil, nondimensional

Table 2

Indexes assessment of physical impacts of projected industrial facilities

Parameters impact	The mathematical formula for calculating the index	Symbols
Noise (i=4)	$I_i = e^{-(e^{(0,025 \cdot L_A - 1)})}$	L_A – noise level, dB; L_{Amax}=0; L_{Amin}=80
Infrasound (i=5)	$I_i = 1 - e^{-(e^{(0,1 \cdot \Delta L - 1)})}$	ΔL – sound pressure level, dB; ΔL_{max}=0; ΔL_{min}=20
Ultrasound (i=6)	$I_i = 1 - e^{-(e^{0.01 \cdot Lvg - 1})}$	Lvg – logarithmic level of vibration, m/s^2; Lvg_{max}=0; Lvg_{min}=110
Electromagnetic impact (i=7)	$I_i = 1 - e^{-(e^{2 \cdot Wгд - 1})}$	$W_{гд}$ – maximum permissible value of the energy flux density, W/ m^2; $W_{гдmax}$=0; $W_{гдmin}$=1
Vibration impact (i=8)	$I_i = 1 - e^{-(e^{(0,018 \cdot Lv - 1)})}$	Lv – logarithmic levels of vibration m/s·10^{-2}; Lv_{max}=0; Lv_{min}=112
Radiation impact (i=9)	$I_i = 1 - e^{-(e^{0.0015 \cdot A_{еф} - 1})}$	$A_{еф}$ – effective total specific activity of natural radionuclides, Bec·kg^{-1}; $A_{ефmax}$=0; $A_{ефmin}$=1350

The authors suggest defining the level of impact on the environmental components on the basis of the values of the indexes. They also suggest assessing the danger category of the facility objects using scales designed to assess the impact of the environment by the projected industrial objects. Some of them are presented in Table 3 (some scale) [8, 9].

To summarize the assessment of impacts on the environment integral index of the environmental danger of the projected industrial facility was developed (3):

$$I = \max \{I_1, \ldots I_i, \ldots I_n\}, \qquad (3)$$

where I – index of the environmental danger of the projected industrial facility; I_i – indexes evaluating the impact (physical, chemical) on the environment.

With the view of the experience, the developed techniques and the minimum necessary conditions the algorithm of environmental risk assessment was suggested. It evaluates the anthropogenic load on the implementation of the designed industrial property: from pre-design studies, design and technology in accordance with the applicable normative documents quantitative assessment of chemical impacts on the components of the environment (air, surface water, soil) and physical impacts are done; the value of quantitative assessment indicators of the impact on the component of the environment is transferred into indexes. The index value is crucial for the decision on the admissibility of design solution for a certain component of the environment, revision or rejection of the project, on provision of the eligibility of the project for each component and environment as a whole the environmental risk is calculated and determined by its level, by the value of the environmental risk level as well as man-caused load of the object on the ecological system is defined.

Table 3

Assessment scale chemical exposure of projected industrial facilities

Range of changing the values of the index	Level of impact	Categories of hazard facility
Atmospheric air		
$0 < I_1 \le 0,37$	Permissible	Safe
$0,37 < I_1 \le 0,45$	Conditionally permissible	Low hazard
$0,45 < I_1 \le 0,66$	Inadmissible	Middle hazards
$0,66 < I_1 \le 0,93$	Inadmissible	Hazardous
$0,93 < I_1 \le 1$	Inadmissible	Especially dangerous
Surface water		
$0 < I_2 \le 0,35$	Permissible	Completely safe
$0,35 < I_2 \le 0,45$	Permissible	Safe
$0,45 < I_2 \le 0,60$	Permissible	Safe
$0,60 < I_2 \le 0,69$	Conditionally permissible	Medium hazardous
$0,69 < I_2 \le 0,80$	Inadmissible	Middle hazards
$0,80 < I_2 \le 0,90$	Inadmissible	Hazardous
$0,90 < I_2 \le 0,91$	Inadmissible	Especially dangerous
$0,91 < I_2 \le 1$	Inadmissible	Extremely hazardous
Soils		
$0 < I_3 \le 0,37$	Permissible	Safe
$0,37 < I_3 \le 0,45$	Conditionally permissible	Middle hazards
$0,45 < I_3 \le 0,93$	Inadmissible	Hazardous
$0,93 < I_3 \le 1$	Inadmissible	Extremely hazardous

According to the concept of EIA and specific manifestations of hazards at the design stage of industrial facilities, mathematical assessment of the environmental risks depending on the designed industrial facility is suggest.

For the calculation of the environmental risk method of environmental risk "index-risk" [10] is modified by way of establishing a functional dependence between developed system indices and normalized levels of environmental risk in the form of probability using nonlinear regression methods. The mathematical calculation of the environmental risk is presented in Table 4.

Table 4

Calculation of the risk of environmental changes from the introduction of industrial facilities in the industrial ecological systems

Environmental risk	Formula	Parameters
Integral environmental risk	$R_E = \sum_{i=1}^{m} r_i$	
Environmental risk on the environment	$r_i = a_i \cdot e^{b_i \cdot I_i}$	a, b – calculated constants: $a_1 = 5,17 \cdot 10^{-9}$, $b_1 = 11,29$ (for air); $a_2 = 4,84 \cdot 10^{-13}$, $b_2 = 21,054$ (for surface water); $a_3 = 6,083 \cdot 10^{-8}$, $b_3 = 5,48$ (for soil); $a_4=1\cdot 10^{-6}$, $b_4 =-37,05$ (for noise), $a_5 = 8 \cdot 10^{-10}$, $b_5 = 7,67$ (for infrasound); $a_6 = 1 \cdot 10^{-8}$, $b_6 = 6,89$ (for ultrasound);$a_{7-8} = 1 \cdot 10^{-8}$, $b_{7-8} = 4,95$ (for electromagnetic, vibration effects); $a_9 = 2,47 \cdot 10^{-9}$, $b_9 = 8,93$ (for radioactive effects).

Evaluation of environmental risks and man-caused load shall be subject to the proposed scale, taking into account the established normal levels of risk for Ukraine

On the basis of the level of environmental risk and man-caused load a decision on the admissibility of the introduction of an industrial facility in the industrial ecological system is taken.

Consequently, the approach to the assessment of man-caused load by determining environmental risks introducing an industrial facility in the industrial ecological system that is based on the calculation of the index. Calculation of the environmental risks enables monitoring of man-caused load and focus not only on damage to human health, but also on other "responses" of the environment.

4. Assessment of man-caused load of Myronivska thermal power plant of Ukraine

The proposed approach to assessment of the man-caused was approbated at the project of reconstruction of Myronivska thermal power plant (TPP) of Ukraine. Heat and power generation in thermal power plants is combined with the emergence of various influences, such as air, water, soil, etc. The impact on the atmosphere occurs during burning of fuel oil and natural gas. Water effect occurs when discharge of various wastewater (after cooling turbine condensers, oil coolers, air, water miscarriages of hydraulic ash removal system), etc. The research of the main sources of influence, as related to the operation of the main and complementary industries is done. Adverse influence of TPP on the environment is associated with the contamination of the air, surface water and soil.

Formula evaluation of the man-caused of TTP on the environment carried out by using the proposed dependency (1)–(3), Table 4.

The results of calculation of man-caused load TTP as assessment indexes and environmental risks are presented in Table 5.

Table 5

The assessment of man-caused load reconstruction project Myronivska TTP

Environment	Qualitative composition	Index estimates		Level of man-caused
		Indexes	Environmental risk	
Atmosphere	NO_2, SO_2, coal ash	I_1=0,645 Inadmissible	$r_1=7{,}6\cdot10^{-6}$ Inadmissible	Inadmissible
Surface water	pH, БСК$_5$, O_2, NH_4^+, NO_3^-, NO_2^-	I_2=0,46 Permissible	$r_2=8{,}15\cdot10^{-9}$ Permissible	Permissible
Soils	Ba, Be, P, Cr, Pb, Ga, Ni, Zn, Zr, Co, Cu, V, Mo, Mn, Li, Sr, As	I_3=0,403 Conditionally permissible	$r_3=5{,}57\cdot10^{-7}$ Conditionally permissible	Conditionally permissible
General assessment of man-caused load		I=0,645 Inadmissible	$R_E=8{,}16\cdot10^{-6}$ Inadmissible	Inadmissible

On the assessment of man-caused load of the facility of the object it is defined that the integral environmental risk is unacceptable and the level of environmental impact is unacceptable, then the overall level of man-caused of Myronivska TPP is not admissible.

For the reconstruction project of Myronivska TPP it is recommended to take measures of improvement. Following the modifying of the reconstruction project activities Myronivska TPP project is conditionally acceptable, recommended for putting into operation, but only on provision of the control of the pollutants of the environment.

5. Conclusions

The mathematical definition depending on environmental risk as an integral criterion in assessing of the man-caused load for the purpose of controlling the level of environmental safety at a design stage of any industrial facility proposed.

On the basis of desirable features a method of forming the index impacts of the individual components of the environment and in general by which the universal dimensionless indices evaluation of environmental impacts (chemical and physical) of hazard is built on the environment from the planned industrial projects. Mathematical formula developed to determine of environmental risk depending on the implementation of an industrial facility in the industrial ecological system for individual components of the environment in general and the implementation of the planned industrial facility in the industrial ecological system that allow to identify dangerous threat in the design phase of industrial facilities.

The proposed approach to assessment of the man-caused on the ecosystem takes into account the physical and chemical impacts of the industrial facility on the stage of its design. The approach makes it possible to evaluate the probability of negative impact of the plant and consider the changes of the components of the environment in keeping with quantities objectives of Ukrainian normative techniques.

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