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METHODOLOGICAL BASICS OF CRITERIAL INTEGRATED ASSESSMENT OF ECOLOGICAL SAFETY MANAGEMENT SYSTEM FUNCTIONING EFFICIENCY OF POWER PLANTS EXPLOITATION PROCESS

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Purpose. Creation of the methodological basis for complex ecological and economical assessment of power plants with piston internal combustion engine exploitation process efficiency. **Methodology.** We have applied the analysis of scientific ant technical literature, ecology safety management systems developing methodology, complex criterial ecological and economical efficiency assessment developing methodology. **Results.** In this paper the algorithm of criterial integrated fuel and ecological assessment of power plants with piston internal combustion engines exploitation efficiency has been developed, described and illustrated. This is an integral part of methodological basis for ensuring the legislative established ecological safety level of such objects. The hierarchical place of developed criteria in structure of construction and life cycle of power plant as well as in structure of corresponding ecological safety management system has been determined. We have also grounded the choice of measurement units for the criteria components. **Originality.** The methodological basis of criterial integrated fuel and ecological assessment of power plants with piston internal combustion engines exploitation efficiency has been developed. **Practical value.** With developed complex criteria the feedback and monitoring of functioning efficiency of the ecology safety management systems can be carried out. **Conclusions**. They are consistent with formulations given in the research results, scientific novelty and practical value. References 15, tables 1, figures 4.

Key words: technogenic and ecological safety, ecological and economical efficiency, criterial assessment, piston ICE, power plants.

МЕТОДОЛОГІЧНІ ОСНОВИ КРИТЕРІАЛЬНОЇ КОМПЛЕКСНОЇ ОЦІНКИ ЕФЕКТИВНОСТІ ФУНКЦІОНУВАННЯ СИСТЕМИ УПРАВЛІННЯ ЕКОЛОГІЧНОЮ БЕЗПЕКОЮ ПРОЦЕСУ ЕКСПЛУАТАЦІЇ ЕНЕРГЕТИЧНИХ УСТАНОВОК

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Розроблено, описано і проілюстровано алгоритм комплексного критеріального еколого-економічного оцінювання ефективності процесу експлуатації енергетичних установок з поршневими двигунами внутрішнього згоряння як неодмінної складової методологічних основ забезпечення законодавчо встановленого рівня екологічної безпеки таких об’єктів, що складає наукову новизну даного дослідження. Розкрито зміст заходів щодо реалізації окремих кроків запропонованого алгоритму. Визначено ієрархічне місце такого комплексного критерію у структурі конструкції енергетичної установки, у структурі її життєвого циклу, а також у структурі відповідної системи управління екологічною безпекою. Обґрунтовано вибір одиниць вимірювання складових такого комплексного критерію. За допомогою такого критерію може здійснюватись зворотний зв'язок і моніторинг ефективності функціонування цієї системи управління екологічною безпекою, що складає практичну цінність даного дослідження.

Ключові слова: техногенно-екологічна безпека, еколого-економічна ефективність, критеріальне оцінювання, поршневі ДВЗ, енергетичні установки.

PROBLEM STATEMENT. *Power plants* (PP), a mechanical power source in which there is a *piston internal combustion engine* (PICE), are powerful sources of ecological danger, in particular – of mass emission of gaseous pollutants with the flow of *exhaust gas* (EG) [1]. Ensuring compliance of PP with PICE with legislatively established *ecological safety* (ES) indicators is one of the priorities as well for experts in the PICE field as for experts in the ES field. Due to the above it is also possible to ensure urbosystems ES, which should also be based on the appropriate methodological support – *ecological safety managing systems* (ESMS). For the quantitative estimation of measures to ensure the urbosystems ES effectiveness considering anthropogenic impact on them there is a necessity of the relevant criteria. Also, using such criteria, it becomes possible to compare competing designs and individual technical solutions for the same designs. Thus, the development of ESMS effective functioning criteria of the PP with PICE process exploitation as an integral part of their *life cycle* (LC), characterized by the greatest possible universality and taking into account in this context as much as possible danger factors, is an actual problem with a significant scientific novelty and practical value.

ANALYSIS OF PREVIOUS STUDIES. The authors of the study [1] have developed the ESMS of PP with PICE exploitation process. The structure of such ESMS contains Stage 4, entitled «The results of ESMS use» which in their turn contains Level 8, called «ES level monitoring and control system» is the final in ESMS structure, closes it by feedback through use of the ES indicators monitoring and control of the ESMS effectiveness as itself [1–3]. Functions of the whole ESMS and its Level 8, which we are interested in, can be described by the following verbal and logical formulas [1, 4]:

F^i_j {N} = [A, B, C] = F {ES ensuring system} = [ES indicators (A) of extracting and processing of waste and pollutants technological process, the source of which are PP with PICE (B), by organization and technical parameters by the way of using of new and improved technologies of ES ensuring (C)]; (1)

F^8 {ES level monitoring and ESMS operating control system} = [monitoring and control of ES of PP with PICE exploitation process indicators level (A) in the appropriate ESMS functioning process of (B), at the rational organization and technical parameters with using of new and improved technologies of ES ensuring (C)], (2)

where A – action of the system or of its component, which gives necessary result;

B – name of the object on which aimed action of the system or of its component;

C – formulation of the special conditions and limitations at which performed action of the system or of its component;

i – number of the ESMS Level;

j – number of the ESMS Level structure element;

N – name of the ESMS Level structure element.

Structure of that ESMS is shown on Figure 1 [1].

EXPERIMENTAL PART AND RESULTS OBTAINED. *Purpose of the study* is creation of the methodological basis for complex ecological and economical assessment of PP with PICE exploitation process efficiency.

Goals of the study are the following:

1. Creation of the criteria for complex ecological and economical assessment of PP with PICE exploitation process efficiency;
2. Creation of the algorithm for such criteria and selection of its components measurement units;
3. Definition of the hierarchical place of such criteria in structure of ESMS, of PP with PICE and of its LC.

Object of the study is the methodological basis for complex ecological and economical assessment of PP with PICE exploitation process efficiency.

Subject of the study is the criteria that give complex characteristic for object of the study.

Solution of the task of the study. The solution of the task of creation of methodological support for implementation of that ESMS Stage are proposed by the way of development of its functioning efficiency criteria, which differs as much as possible universality. The proposed conception of that criteria development and its application algorithm involves the following sequence of Steps shown in the Table 1.

Stage 1 → Initial data for ESMS creation		**Stage 2** → Improved and new technologies for ES level ensuring which using by ESMS		**Stage 3** → Organization and performing of technological processes for ES level ensuring which using by ESMS		**Stage 4** →↵ Results of ESMS application	
Level 1 →	**Level 2** →	**Level 3** →	**Level 4** →	**Level 5** →	**Level 6** →	**Level 7** →	**Level 8** →↵
Identification of ecological danger factors sources and analysis of low and normative data base	Classification of ecological danger factors with taking into account their genesis and significance	Development of improved and new preparation technological processes	Development of improved and new equipment for technological processes implementation	Organization and management of ESMS	Manufacturing and technological processes which ensure specified ES level	Output results of ESMS application: values of ES factors and obtaining of designated purpose production	System of monitoring and control of ES level

Figure 1 – Scheme of ESMS of PP with PICE exploitation process

Table 1 – Sequence of Steps of the algorithm

Step	Name and gist of the Step
A	«**Basic version of the object**». Quantitative estimation in absolute and relative units of values level of complex technical and economical mode or/and middle exploitation indicators of basic version of PP with PICE, that is before implementation of events for increasing of its ES level.
B	«**Action of ESMS on the object**». Development and implementation of events in the ESMS structure for ensuring of certain ES level of PP with PICE exploitation process.
C	«**Modernized version of the object**». Quantitative estimation values level of such indicators complex for modernized version of PP with PICE that is after implementation of events for increasing its ES level based on new or improved methods and means.
D	«**Response of the object to ESMS action**». Definition of absolute and relative difference of values such indicators complex for basic and modernized versions of PP with PICE that is offered to consider the ESMS functioning efficiency criteria.
E	«**Normalization of the ESMS functioning efficiency criteria**». Comparison of obtained difference of such indicators complex values with its legislative limited values or developed scale and conclusion of certain findings based on comparison of that results.
F	**«Correction of action of ESMS on the object»**. Correction of kind or sequence of events for ES level ensuring in the ESMS structure and also intensity or nature of impact of individual event.
G	**«Feedback»**. Rationalization of ESMS functioning efficiency criteria value in iteration process with variation of parameters values of technological processes and executive organs that ensure necessary ES level.

Thus, proposed algorithm is closed with feedback (i.e., cyclic) and is not autonomous regarding ESMS as itself, because it contains Steps B and F, with which its interaction with the ESMS is implemented. Therefore, it can be called integrated in ESMS. Here Step B is the source of the new information in the algorithm and the Step F is the source of information for ESMS.

For realizing the Step A «Basic version of the object» and Step C «Modernized version of the object» of developed algorithm, taking into account specific features of technical object on which acts ESMS, using complex fuel and ecological criteria of prof. I.V. Parsadanov [5] and other criteria that is similar to it developed on its basis or likeness are proposed. As a mode initial data for such assessment the results of experimental or computational researches, which is based on known, improved or developed methodic should be used, such as in research [6]. For obtaining the middle exploitation values of initial data the test methodic, which appropriate exploitation model of PICE or PP should be used because of fact that it contains stationary, transition or mixed operation modes list with its characteristics (for PICE it is values of crankshaft speed, torque and weight factor etc.) and also appropriate techniques for experimental obtained data processing. In the case of impossibility of carrying out of experimental studies for specific exploitation models and availability data from previous studies for obtaining the necessary initial data the mathematical apparatus of approximation (for example, least square or linear regression methods), interpolation or extrapolation can be used [4].

For implementation of Step B «Action of ESMS on the object» of the algorithm it is proposed to use the results of other ESMS Steps described in [1, 2].

For implementation of Step D «Response of the object to ESMS action» of the algorithm the difference of complex of technical, economical and ecological indicators values for basic and modernized versions of PP with PICE actually considered the criteria of ESMS operation efficiency of PP with PICE exploitation process – Ω_{ESMS} is proposed [5]. Composition of complex of technical, economical and ecological PICE operational indicators that can be taking into account by such criteria has to be as comprehensive as possible, what determines criteria universality level. For that it must be in accordance with paragraphs of ecological danger factors classification that created in research [1] and presented on Fig. 2. In this case the criteria of ESMS operation efficiency of PP with PICE exploitation process are defined by formula [4]:

$$\Omega_{ESMS} = \left(\mathrm{E}_M - \mathrm{E}_B\right) / \mathrm{E}_B, \quad (3)$$

where E_M and E_B – accordingly monetary expenses for modernized and basic versions of PP with PICE, $.

Justification of measurement units choice for Ω_{ESMS} criteria – US Dollars ($) is presented in [4].

This decision is due to the following circumstances.

Firstly, by definition, money is the commodity of maximum liquidity and the universal equivalent of the value of goods and services [7].

Secondly, the presence of the successful experience of applying well-known approach to assessment of technical, economic and ecological indicators of PICE developed by prof. I.V. Parsadanov as a part of the methodology of calculation of the fuel and ecological criteria K_{FE} [5].

Thirdly, not all of monetary expenses components are possible to bring to form the dimensionless quantity β and, moreover, to give them a physical meaning of average operational efficiency specific mass hour fuel consumption $g_{e\ av\ exp}$, as in the case K_{FE} [5].

In research [5] monetary expenses, which included in K_{FE} criteria structure are expressed in Ukrainian

Hryvnia (₴). But in this case there appears the problem of assessing the effectiveness of measures to ensure the ES level of PP with PICE which are in operation for a long time. So, for the case of raising the ES level of diesel 2Ch10,5/12 by equipping it of exhaust system with DPF, developed in Piston Power Plants Dept. of A.M. Podgorny Institute for Mechanical Engineering Problems of NAS of Ukraine with the participation of staff members of the Applied Mechanics Dept. of Technogenic and Ecological Safety Faculty of National University of Civil Defense of Ukraine [6, 8–10], a direct comparison of K_{FE} criterion values for the basic (diesel without DPF) and modernized (diesel with DPF) version to perform in the Ukrainian Hryvnia is difficult.

This is due to the following circumstances.

Firstly, diesel 2Ch10,5/12 (D21A1), which was used as a generator of aerosol of PM in the EG in these studies, released in the middle of the 80-years of the XX century, modern its modification produced by the Vladimir Tractor Plant (Russian Federation) and has significant constructive differences (e.g., electronic fuel supply control system). In this case to estimate accurately the total operating time and the residual motoresource, prehistory and features of its exploitation, maintenance and repair measures and also, accordingly, its current technical condition and correlate it with any value indicator is extremely difficult.

Secondly, at the time of its release, such monetary unit as the Ukrainian Hryvnia did not exist, and the unit in which to express its cost parameters – USSR Ruble – does not exist at present; monetary unit in which its cost was estimated at the time when motor test bench was equipped with this diesel engine – Ukrainian Coupon-Karbovanets – neither exists no longer; and the current modification of this diesel engine is estimated in Russian Rubles.

Thirdly, for some reason the Ukrainian Hryvnia exchange rate against major freely convertible (so-called hard) currencies is very unstable. So, at the time of introduction into circulation Ukrainian Hryvnia (1996), its rate against the US Dollar ($) amounts to less than 2 ₴/$, at the beginning of development of DPF concept (2008) – about 5 ₴/$, at the time of obtaining experimental data for the study [6] (2013) – about 8 ₴/$, at the time of mathematical models [8 – 10] creation (2014) – about 12 ₴/$, at the moment (October 2016) – about 26.5 ₴/$. To predict the behavior of this macroeconomic indicator with reasonable accuracy for at least six months in advance is impossible, not to mention the longer term.

In connection with the above considerations, it seems rational to express the monetary expenses values E in the formula (3) that are forming Ω_{ESMS} criteria value, in one of the widely used in Ukraine freely convertible world reserve currencies – Euro or US Dollar. However, only the last one has a history that completely covers the PICE history from the birth of the idea (1807 de Rivas engine, 1860 Lenoir engine, 1863 two-stroke Otto engine,1876 four-stroke Otto engine, 1880 Kostovich engine, 1897 Diesel engine) and to the present day.

In this case we should take into account that purchasing capacity of the US Dollar throughout its existence since the creation of the first PICE to the present day was not constant too due to manifestations of inflation phenomenon, which can be accounted by applying the Consumer Price Index CPI [7].

In order to enable comparative studies of different energy sources for PP, such as PICE and separately photoelectric converter (PEC) based on nanostructured semiconductors [11], or a complex of PEC and supercapacitor or a complex of PEC, supercapacitor and electric motor, in the structure of the developed criterion Ω_{ESMS} monetary expenses for fuel it must be converted into energy or power units.

It should also be noted that the equipping diesel by the DPF affects the value of K_{FE} criteria as a part of Ω_{ESMS}, both positively – by reducing the PM mass emissions from the EG flow (and corresponding money expenses for compensation for impact of that ecological danger factor on environment or urbosystem), and negative – due to fuel consumption increase to overcome the DPF hydraulic resistance [4, 6, 10].

To implement Step E «Normalization of the ESMS functioning efficiency criteria» of the algorithm it is proposed to use the data of regulatory legal acts that are in force in the territory, where PP operation is carried out, such as the UNECE Regulation number 49 or 96 [1].

To implement Step F «Correction of action of ESMS on the object» of developed algorithm it is proposed to base on specific characteristics of the particular measures to ensure the ES level of PP with PICE process exploitation or complex of such measures.

To implement Step G «Feedback» of developed algorithm it is proposed to use experiment planning method [12], mathematical apparatus of multi-criteria optimization [13], as well as the mathematical apparatus of fuzzy logic, namely Harrington generalized desirability function using psychophysical scales [14, 15].

When developing Ω_{ESMS} criteria we must take into account the following aspects of the hierarchical structure of ESMS, PP and its LC.

The whole LC of PP with PICE is traditionally divided into sequential chain of phases, a division into which is found no common approach among researchers. In the light of specifics of this problem and the above considerations it makes sense to combine them in blocks given in Fig. 3.

When developing Ω_{ESMS} criteria it is also necessary to take into account the features of PP as is and PICE as they energy sources.

Firstly, one and the same PICE can be used as actuator for different types of PP (for example, autotractor diesel engines), that is used by various exploitation models.

Secondly, one PP can contain more than one PICE (e.g., mobile concrete mixer with a drive mixer by a separate PICE, articulated lorry consisting of tractor and power unit with electric generator, water pump or air compressor on board, etc.) that can be exploited simultaneously, separately and with some overlap of each other's time.

Thirdly, PP as itself, excluding the presence in its composition PICE and aggregates of its systems, made outside the engine compartment, are also sources of ecological and technogenic danger, and must be both qualitatively and quantitatively characterized by their own factors, the criteria for these evaluations also require development or modifications.

Fourthly, in some PP there is PICE, what is not the primary or main source of mechanical energy, or produces such energy discontinuously (e.g., hybrid vehicles), that is its operation model is fundamentally different from a conventional as well by the structure, as by parameters of individual modes of PICE exploitation modes.

Due to the above, especially it should be noted that the proposed Ω_{ESMS} criteria in the proposed formulation takes the following hierarchical place in the structures of LC and the composition of PP: firstly, characterizes only Block II of PP with PICE LC «exploitation»; secondly, characterizes ES level only of part PP, namely PICE and systems units that its service, as shown in Fig. 4.

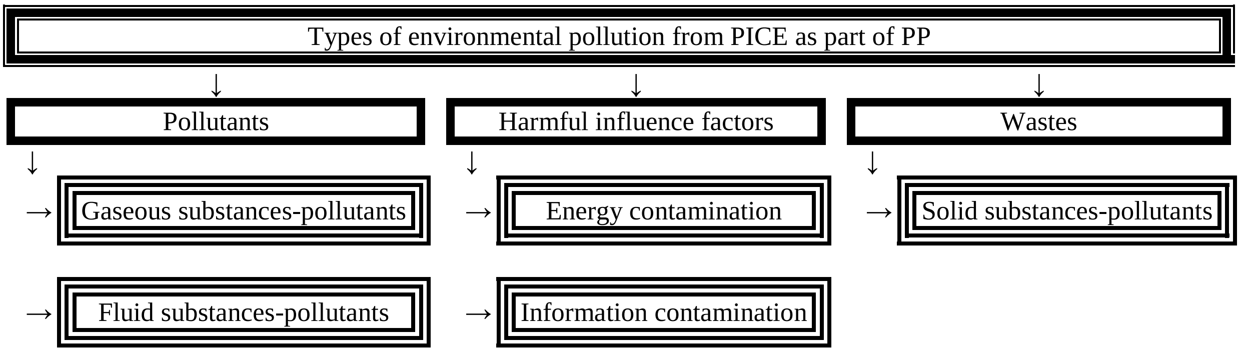

Figure 2 – Classification of Types of environmental pollution from PICE as part of PP [1]

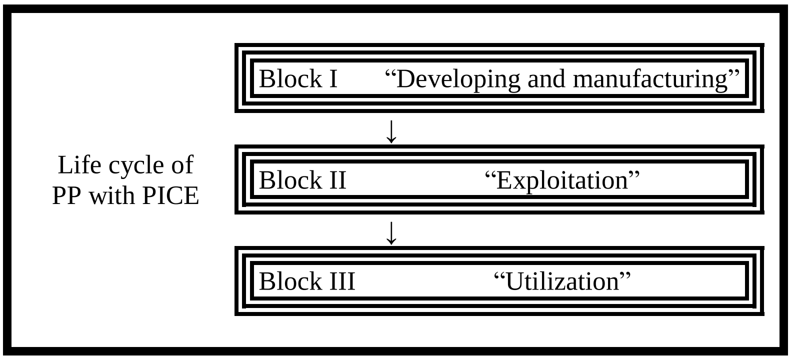

Figure 3 – Dividing the PP with PICE life cycle into blocks suitable for use in the development ESMS process

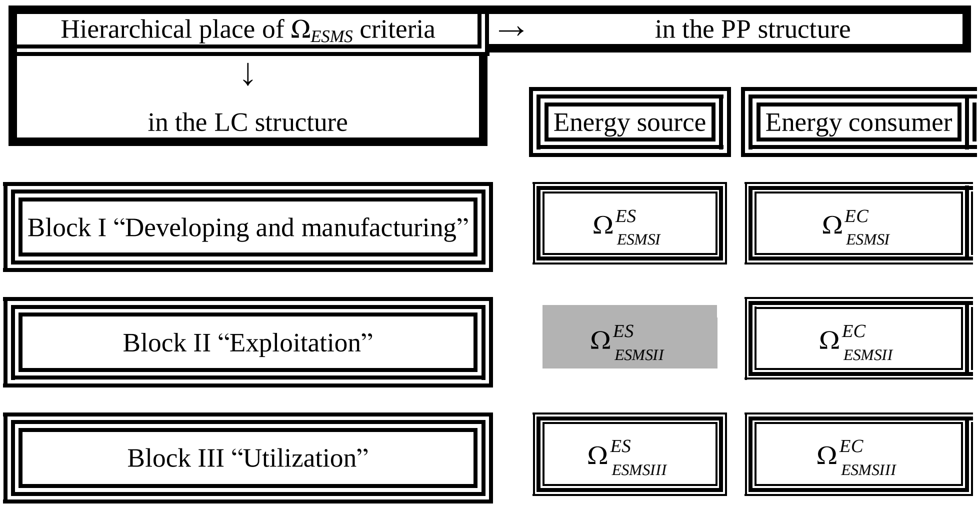

Figure 4 – Hierarchical place of Ω_{ESMS} criteria

In Fig. 4 there are the following notations: indices I, II and III are marked Ω_{ESMS} criteria for the Block I, Block II and Block III of LC, respectively, while the index ES and EC is designated Ω_{ESMS} criterion for PP energy sources (e.g., PICE and units of its systems, made by outside the engine compartment) and its energy consumers (PP all executive organs, parts of its skeleton, control and measuring equipment, etc.), respectively.

Therefore, for the ESMS of the PP with PICE exploitation process criterion of efficiency of its functioning Ω_{ESMS} can be expressed by the following formula:

$$\Omega_{ESMSII}^{PP} = f\left(\sum_{j=1}^{m}\Omega_{ESMSII}^{ES}; \sum_{k=1}^{n}\Omega_{ESMSII}^{EC}\right), \qquad (4)$$

where f – some mathematical function that linking moieties of the Ω_{ESMS} criteria;

j – number of energy source in the PP structure;

k – number of energy consumer in the PP structure;

m – quantity of energy source in the PP structure;

n – quantity of energy consumer in the PP structure.

Summing up the above arguments, the structure of the algorithm of estimation the efficiency of ESMS of PP with PICE exploitation processes and its place in the ESMS structure is shown in Fig. 5.

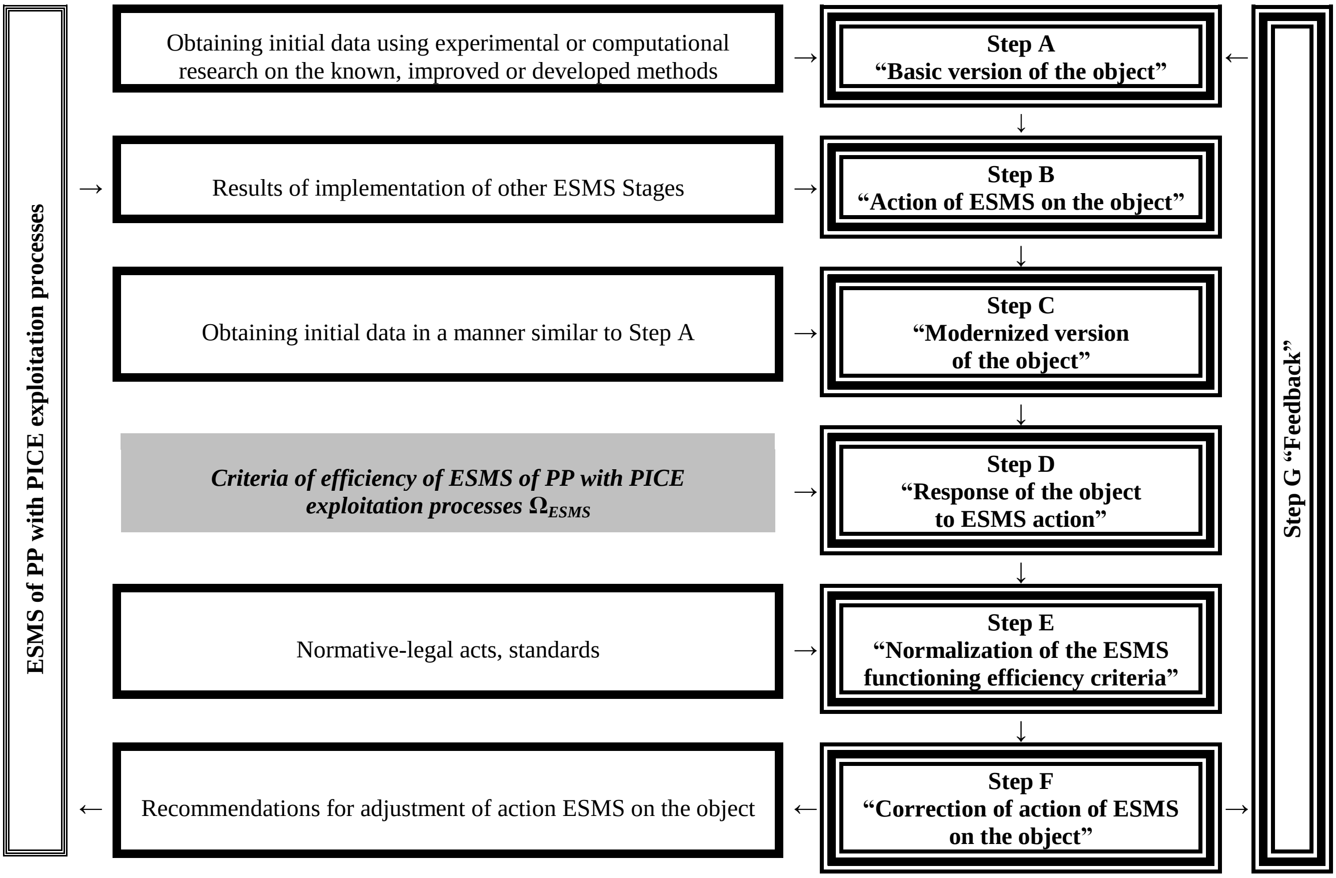

Figure 5 – Algorithm of estimation the efficiency of ESMS of PP with PICE exploitation processes

CONCLUSION. Thus, in the study methodological basis of the criteria for evaluating the ESMS functioning effectiveness of PP with PICE operation process has been developed, in what the *scientific novelty* of the study results consists. It is equal to the difference between the values of the complex technical, economic and ecological indicators of basic and modernized versions of such objects. It is the final in the structure of ESMS, closes it with feedback through the use of monitoring ES indicators and monitoring the effectiveness of the ESMS as itself, in what the *practical value* of the study results consists. hierarchical place of such a criterion in the structure of ESMS, PP and its life cycle have been determined.

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МЕТОДОЛОГИЧЕСКИЕ ОСНОВЫ КРИТЕРИАЛЬНОЙ КОМПЛЕКСНОЙ ОЦЕНКИ ЭФФЕКТИВНОСТИ ФУНКЦИОНИРОВАНИЯ СИСТЕМЫ УПРАВЛЕНИЯ ЭКОЛОГИЧЕСКОЙ БЕЗОПАСНОСТИ ПРОЦЕССА ЭКСПЛУАТАЦИИ ЭНЕРГЕТИЧЕСКИХ УСТАНОВОК

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Разработан, описан и проиллюстрирован алгоритм комплексной критериальной эколого-экономической оценки эффективности процесса эксплуатации энергетических установок с поршневыми двигателями внутреннего сгорания как неотъемлемой составляющей методологических основ обеспечения законодательно установленного уровня экологической безопасности таких объектов, что составляет научную новизну данного исследования. Раскрыто содержание мероприятий по реализации отдельных шагов такого алгоритма. Определено иерархическое место такого комплексного критерия в структуре конструкции энергетической установки и структуре ее жизненного цикла, а также в структуре соответствующей системы управления экологической безопасностью. Обоснован выбор единиц измерения составляющих такого комплексного критерия. При помощи такого критерия может осуществляться обратная связь и мониторинг эффективности функционирования этой системы управления экологической безопасностью, что составляет практическую ценность данного исследования.

Ключевые слова: техногенно-экологическая безопасность, эколого-экономическая эффективность, критериальная оценка, поршневые ДВС, энергетические установки.

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