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SELECTION OF CRITERIAL APPARATUS FOR COMPLEX ASSESSMENT OF ECOLOGICAL SAFETY LEVEL OF EXPLOITATION PROCESS OF POWER PLANTS

Present paper describes the results of selection of mathematical apparatus for the complex calculation criterial assessment of ecological safety level of exploitation process of power plants which equipped with piston internal combustion engine based on analysis of known ones. Proposed the classification of such mathematical apparatuses that most suitable for objects of assessment on the basis of type of set of used initial data. Implemented the analysis of advantages and lacks of such apparatuses and methodics of their application. Grounded of priority of application of types of such apparatuses. Grounded of recommendation of application of complex fuel and ecological criteria of prof. Parsadanov as the only one that operates with full set of legislative normalized factors of ecological safety, have the physical sense and taking into account fuel consumption of engine. Determined the limits of application of concept «accident-free exploitation process». Analyzed of influence of fuel consumption of engine on factors of ecological safety of accident-free exploitation process of assessed objects. Determined that the recommended criterial apparatus is deprived of opportunity to take into account of legislative established values of influencing factors, obtain of their regime values and accounting of its wider spectrum.

Keywords: technogenic and ecological safety, complex criterial assessment, power plant, engine.

Problem statement. On combat duty of subdivisions of State Emergency Service of Ukraine are large number of power plants (PP) (units of fire, emergency and rescue technique) which equipped with piston internal combustion engine (PICE), namely diesel, as the main source of mechanical energy. Every unit of PICE is source of ecological danger, namely mass emissions of pollutants with exhaust gas (EG) flow, namely particulate matter (PM). The most effective way for increasing of ecological safety (ES) level of exploitation process of such objects through bringing of indicators of their EG toxicity to legislative normalized requirements is developing and realization of appropriate ecological safety management systems (ESMS). In this case, the material basis of complex solving of this problem is development and implementation of neutralization systems for legislative normalized pollutants in EG flow and its aggregates, namely particulate matter filters (PMF) [1, 2]. For qualitative and quantitative assessment of efficiency of application of already existing or new developed neutralization systems and their aggregates requires to applying of appropriate mathematical apparatus and methodic of its using. In connection with this, it seems relevant to substantiate of selecting of such apparatus with appropriate methodic of its application.

Statement of the problem and its solution. *Purpose of the study* is substantiation of selection of criterial mathematical apparatus for assessment of efficiency of application of events and technical solutions for increasing of ES level of exploitation process of PP with PICE.

Object of the study is ES level of accident-free exploitation process of PP with PICE.

Subject of the study is mathematical apparatuses and appropriate methodic of its using for calculated assessment of object of the study.

Tasks of the study are:

1. Analysis of already existing mathematical apparatuses for criterial calculated assessment of object of the study.
2. Classification of mathematical apparatuses with taking into account of specific features of assessed objects.
3. Substantiation of priority of application of such mathematical apparatuses for case of PP with PICE.
4. Determination of influence of PICE fuel consumption as influencing factor on factors which characterized object of the study.
5. Substantiation of selection of the most appropriate mathematical apparatuses for criterial calculated assessment of object of the study from number of known.

Analysis of science and technical literature on topic of the study allows to determinate six already existing different criterial mathematical apparatuses which potentially can be applied for complex achieving of purpose of the study.

Based on results of this analysis proposed the classification of criterial mathematical apparatuses which presented on the figure 1.

Let's consider mathematical apparatus of criterias showed on figure 1.

Parsadanov complex fuel and ecological criteria K_{FE} describes by formula (1) and its components – by formulas (2) – (8) [3].

$$K_{FE} = \eta_{eme} \cdot (1-\beta) = \eta_{eme} \cdot \left(1 - Z_e / \left(Z_f + Z_e\right)\right); \quad (1)$$

$$\eta_{eme} = 3600 / \left(H_u \cdot g_{eme}\right); \quad (2)$$

$$g_{eme} = \sum_{i=1}^{z} \left(G_{fi} \cdot WF_i\right) / \sum_{i=1}^{z} \left(N_{ei} \cdot WF_i\right); \quad (3)$$

$$Z_f = g_{eme} \cdot P_f ; \quad (4)$$

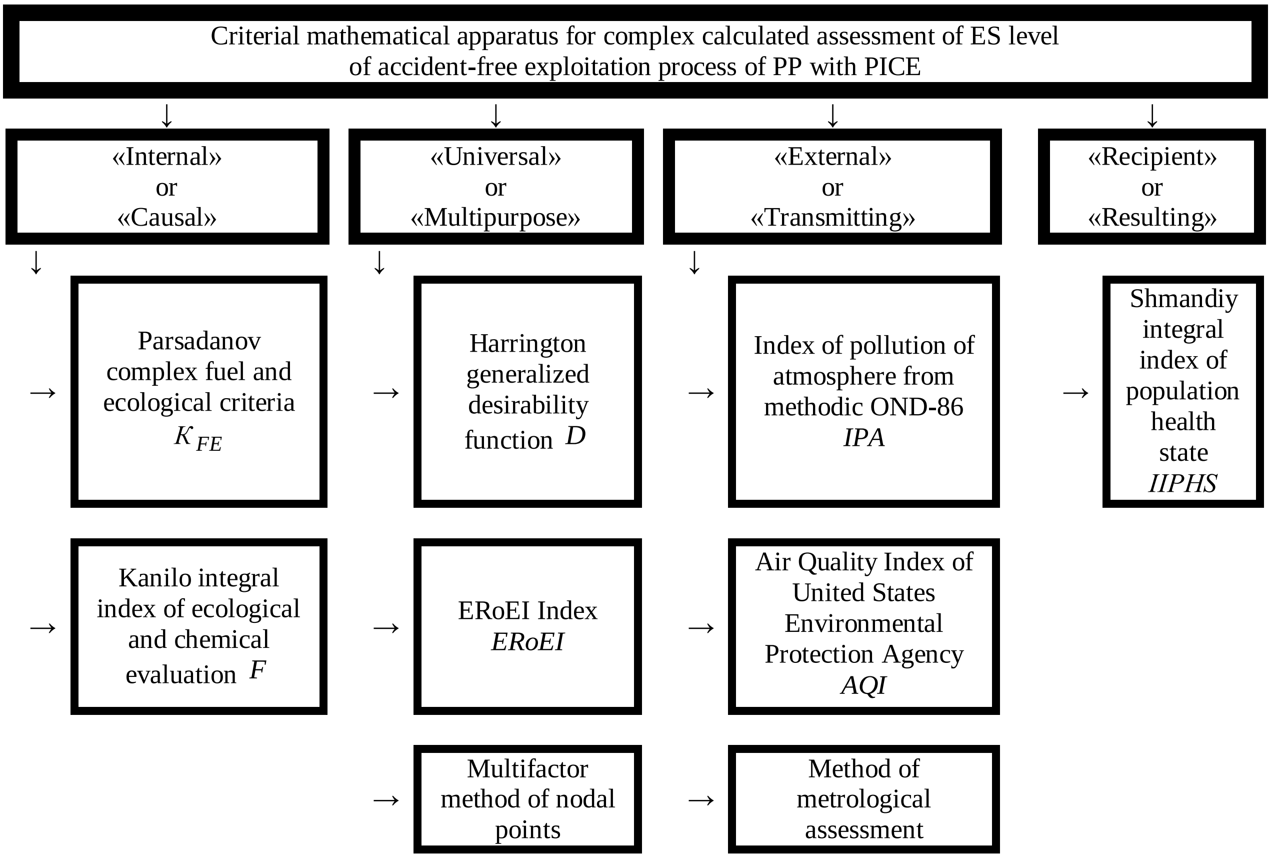

Figure 1 – Classification of criterial mathematical apparatus for complex calculated assessment of ES level of accident-free exploitation process of PP with PICE

$$Z_e = \sum_{i=1}^{z}\left(G_{fi}\cdot WF_i\cdot U_{ei}\right) / \sum_{i=1}^{z}\left(N_{ei}\cdot WF_i\right); \quad (5)$$

$$N_{ei} = M_{Ti}\cdot n_{csi} / 9550; \quad (5a)$$

$$U_{ei} = \delta\cdot\sigma\cdot f\cdot g_{pri}; \quad (6)$$

$$g_{pri} = \sum_{k=1}^{h}\left(A_k\cdot G_{pki} / G_{fi}\right); \quad (7)$$

$$k = \{NO_x, PM, C_nH_m, CO\}, \quad (8)$$

where index i marks individual representing i-th operational regime of exploitation model of PICE; η_{eme} – middle exploitation value of effective efficiency coefficient of PICE; β – coefficient of relative exploitation ecological monetary costs; Z_e, Z_f and Z_{fe} – ecological damage compensation monetary costs, motor fuel monetary costs and total fuel and ecological monetary costs, \$/(kW·h); g_{eme} – middle exploitation value of specific effective mass hourly fuel consumption by diesel engine, kg/(kW·h); H_u – motor fuel lower heat of combustion; WF – weight factor of operational mode in exploitation model (relative lobar engine run time on i-th polygon of exploitation model); N_{ei} – effective power of PICE, kW; G_f – mass hourly fuel consumption of PICE, kg/h; P_f – price of motor fuel mass unit, \$/kg; U_e – ecological damage compensation monetary valuation, \$/kg; δ – dimensionless index of relative dangerous of pollution for various territories; f – dimensionless coefficient, which taking into account the character of EG dispersion in atmosphere; $\sigma = P_f$ – dimension coefficient for converting scoring assessment of damage in the monetary; g_{pr} – specific effective mass hourly emission of k-th pollutant with PICE EG flow, kg/(kW·h); G_{pk} – mass hourly pollutant emission with PICE EG flow, kg/h; A_k – dimensionless index of relative aggressiveness of k-th pollutant as a EG component; $h = 4$ – number of legislative normalized pollutants in EG flow; M_T – torque of PICE, N m; n_{cs} – crankshaft speed of PICE, rpm.

Kanilo integral index of ecological and chemical evaluation F describes by formula (9) [4].

$$F_j = 10^{-6}\cdot\left\{\frac{M_{CO}}{[CO]} + \frac{M_{CH}}{[CH]} + a\cdot\frac{M_{NO_x}}{[NO_x]} + b\cdot\frac{M_{Soot}}{[Soot]}\right\} +$$

$$+\left\{c\cdot\frac{M_{SO_2}}{[SO_2]} + d\cdot\frac{M_{b(a)p}}{[M_{b(a)p}]}\right\}, \text{ m}^3\text{/test}, \quad (9)$$

where M_j – total mass emission of pollutant in PICE EG flow during test period on European driving cycle, g/test; $[j]$ – maximum permissible daily average concentration of j-th pollutant in air of populated areas, mg/m^3; a, b, c, d – coefficients which accepted based on experimental estimates.

Index of pollution of atmosphere from methodic OND-86 IPA (or dimensionless concentration q) describes by formula (10) and its components – by formulas (11) [5].

$$q = \sum_{i=1}^{n} \frac{c_i}{MPC_i}; \tag{10}$$

$$c = \frac{A \cdot M \cdot F \cdot m \cdot n \cdot \eta}{H^2 \cdot \sqrt[3]{V_1 \cdot \Delta T}}, \tag{11}$$

where index i represent i-th pollutants that polluting of atmospheric air; c – mass concentration of pollutant, mg/m^3; MPC – maximum permissible concentration (MPC) of pollutant, mg/m^3; A – dimensionless coefficient that depends from temperature stratification of atmosphere; M – mass secondly emission of pollutant, g/s; F – dimensionless coefficient that taking into account sedimentation rate of pollutants in atmospheric air; m and n – dimensionless coefficients that taking into account conditions of output of gas and air mixture from mouth of source of emission; η – dimensionless coefficient that taking into account influence of relief of terrain; H – height of source of emission under the Earth level, m; ΔT – difference between temperature of ejected gas and air mixture and temperature of environment atmospheric air, °C; V_1 – volume secondly flow rate of gas and air mixture, m^3/s.

Air Quality Index of United States Environmental Protection Agency AQI describes by formula (12) [6].

$$AQI = \frac{AQI_{high} - AQI_{low}}{C_{high} - C_{low}} \cdot \left(C - C_{low}\right) + AQI_{low}, \tag{12}$$

where C – multiplicity of excess of normative value of MPC of pollutant; C_{high} – limit of multiplicity of excess of normative value of MPC which is greater than or equal to value C; C_{low} – limit of multiplicity of excess of normative value of MPC which is less than value C; AQI_{high} – value of index which corresponding to value C_{high}; AQI_{low} – value of index which corresponding to value C_{low}.

ERoEI Index (Energy Returned on Energy Invested) *ERoEI* describes by formula (13) and its components – by formulas (14) [7].

$$ERoEI = \frac{E_{Consumable}}{E_{Expended}} = \frac{NEG}{E_{Expended}} + 1; \tag{13}$$

$$NEG = E_{Consumable} - E_{Expended}, \tag{14}$$

where $E_{Consumable}$ – energy (work) produced by source (resource) which suitable for consumption (useful, exergy); $E_{Expended}$ – energy (work) expended for obtaining of source; NEG – Net Energy Gain, J.

Harrington generalized desirability function D describes by formula (15) and its components – by formulas (16) – (18) [8].

$$D = \sum_{i=1}^{n}\left(D_i \cdot WF_i\right) / \sum_{i=1}^{n} WF_i; \tag{15}$$

$$D_i = \sqrt[\sum_{k=1}^{n} \upsilon_k]{\prod_{k=1}^{n} d_{ki}^{\upsilon_k}}; \tag{16}$$

$$d_{ki} = exp\left[-exp\left(a_{ki} + b_{ki} \cdot r_{ki}\right)\right]; \tag{17}$$

$$k = \left\{g_{NOxri}, g_{PMri}, g_{CnHmri}, g_{COri}, g_{ei}\right\}. \tag{18}$$

where k represent k-th influencing factors; d – partial desirability function; r – value of influencing factor; a and b – constant coefficients which correlating the value of influencing factor with the reference points of desirability scale; v – degree index, accounting of ponderability of influencing factor.

Shmandiy integral index of population health state *IIPHS* describes by formula (19) and its components – by formulas (20) – (21) [9].

$$IIPHS = ABA - IBA, \tag{19}$$

where ABA – actual biological age, years; IBA – independent biological age, years.

$$ABA = \gamma + \sum_{i=1}^{5}\left(\alpha_i \cdot \Pi_i\right) - \sum_{j=1}^{3}\left(\beta_j \cdot I_j\right); \tag{20}$$

$$ABA = 0{,}58CE + 17{,}24, \tag{21}$$

where α, β, γ – empirical coefficients; Π_1 – subjective health indicator by questionnaire; Π_2 – systolic blood pressure; Π_3 – diastolic blood pressure; Π_4 – pulse blood pressure; Π_5 – duration of breath retention after deep inspiration; I_1 – vital volume of the lungs; I_2 – duration of breath retention after deep exhalation; I_3 – static balancing; CE – calendar age, years.

Method of metrological assessment describes by formulas (22) – (24) [10].

$$\begin{cases} V = (-\infty; V_{me} - \sigma_V) \Rightarrow G = 4; \\ V = [V_{me} - \sigma_V; V_{me}] \Rightarrow G = 3; \\ V = [V_{me}; V_{me} + \sigma_V] \Rightarrow G = 2; \\ V = (V_{me} + \sigma_V; +\infty) \Rightarrow G = 1, \end{cases} \tag{22}$$

where V – reduced emission of pollutant, tons/km^2; V_{me} – mathematical expected value of emission of pollutant, tons/km^2; σ_V – standard deviation of emission of pollutant, tons/km^2; G – number of group of locality by ecological safety level (1 – high; 2 – medium; 3 – low; 4 – minimal).

$$V_{me} = \frac{1}{N} \cdot \sum_{i=1}^{N} V_i \; ; \qquad (23)$$

$$\sigma_V = \sqrt{\frac{1}{N-1} \cdot \sum_{i=1}^{N} \left(V_i - V_{me}\right)^2} \; , \qquad (24)$$

where N – amount of measures of reduced emission of pollutant; i – number of measure.

Multifactor method of nodal points [11] allows complex assessing of impact of relative values of influencing ES factors on values of some criteria of ES level using internal universal scale with one reference (nodal) point. Multidimensional surface which reflects that influence can be described by formula

$$g = \prod_{i=1}^{n} \varphi_i\left(x_i\right); \qquad (25)$$

and for obtaining of absolute values of the criteria can be used formula

$$G = G_0 \cdot g \; , \qquad (26)$$

where g – relative value of ES level criteria; φ – function that takes into account of influence of value of i-th ES factor on value of ES level criteria; x – value of i-th ES factor; G – absolute value of ES level criteria; G_0 – value of i-th ES factor in nodal point.

As it can be seen from data presented on figure 1 the main classification attribute in proposed classification is type of set of initial data using for calculated assessment. According to proposed principle:

– to the number of «internal» of «causal» criterial apparatuses we propose to include that which operates with regime and/or middle exploitation values of data about containing pollutants in PICE EG flow obtained by calculation or experimental way, for example like in studies [12, 13];

– to the number of «external» of «transmitting» criterial apparatuses we propose to include that which operates with data about containing pollutants in atmospheric air of urbanic system obtained by calculation or experimental way;

– to the number of «universal» or «multipurpose» criterial apparatuses we propose to include that mathematical apparatuses of which equally successful operates with both types of initial data set;

– to the number of «recipient» or «resulting» criterial apparatuses we propose to include that operates with data about values of response of objects of influence of ES factors.

To the number of advantages of «internal» criterias it can be attributed the possibility of assessment of ES level of exploitation process of individual unit of technique. It especially relevant for technique of special purpose, fleet of which are a small part of vehicle fleet of settlement or its district, where fire station is based, and to compare obtained results with standards of toxicity of PICE EG flow. To the number of lacks of «internal» criterias it can be attributed the difficulty of obtaining of initial data set by experimental way, namely necessary of availability of engine test bench with loading machine and specific measuring equipment.

To the number of advantages of «external» criterias, as opposed to «internal», it can be attributed the possibility of assessment of ES level of urbanic system as a whole and to compare obtained results with values of maximum permissible concentration of pollutant in atmospheric air. It criterias also use as initial data set the information from net of meteorology stations and points of observing, from remote satellite scanning of Earth surface and so on. To the number of lacks of «external» criterias it can be attributed the principal impossibility of assessment of individual contribution of individual unit of special technique in pollution of environment.

The common advantage of «internal» and «external» criterias is structure of highly specialized well-established they mathematical apparatuses and also well-developed methodics of the application. But this feature also makes them unusable for assessment of ES level of any other objects.

«Universal» criterias, as opposed to other two, just differ in flexibility of they mathematical apparatuses and variability of methodic of the application. Wherein for accounting of ES factors which radically differ from mass hourly emission of pollutants in PICE EG flow (namely noise, vibration, informational and energetic pollution, liquid pollutants and solid wastes [1]) it is impossible to do without using of «universal» criterial apparatuses. But in this case it necessary to tune settings of the mathematical apparatus and to adjust methodic of its application.

«Recipient» or «resulting» criterial apparatuses characterized by that advantages what describes indirectly the final result of impact of manifestation of ES factors on the recipient, that is on parts of environment on protection of which are aimed the events which developed in corresponding ESMS. Thus, the analysis of such information can give the most objective picture of the ES level of urban system and its components. But that approach characterized by substantial disadvantages, the main of which are difficulty and high cost of obtaining of initial data set and also essential differences between types of initial data set for different kinds of recipients as well as for different units of the same kinds recipients

Based on worded above we should note that there is the priority of application of criterial apparatuses in descending order for the case of PP of special purpose (fire, emergency and rescue technique) which equipped with PICE as it shown in figure 2.

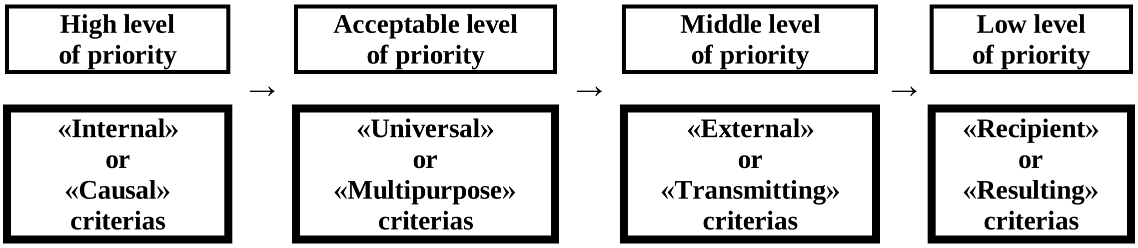

Figure 2 – Priority of application of criterial apparatuses in descending order for the case PP of special purpose, namely fire, emergency and rescue technique which equipped with PICE

Wherein before tuning of settings of mathematical apparatuses of «universal» criterias (as more perspective and flexible) it should be estimated individual aspects of mathematical apparatus of «internal» criterias (as more priority) and to adjust methodic of its application for cases of new and already existing models of PICE of special technique and aggregates of systems for pollutant neutralization in EG flow, as it shown in studies [14, 15].

In connection with worded above it should be selected priority of application between two «internal» criterial apparatuses, presented in figure 1, namely Parsadanov complex fuel and ecological criteria K_{FE} and Kanilo integral index of ecological and chemical evaluation F.

Analysis of their mathematical apparatuses makes it possible to recommend the use of criteria K_{FE} as one that, as opposed to criteria F, operates only with set of initial data, requirements to which are legislative normalized in Ukraine (UNECE Regulations # 49 and # 96 [16, 17]) and their list is a complete set.

In addition, of the two compared criterial apparatuses only Parsadanov criteria K_{FE} has the physical meaning, namely middle exploitation value of PICE effective efficiency coefficient with taking into account monetary costs for compensation of ecological damage from pollution of environment by legislative normalized pollutants in EG flow. In case of PICE with ideal ecological indicators, that is with zero emissions of pollutants, value of the criteria equal to middle exploitation value of PICE effective efficiency coefficient η_{eme}. In connection with this it can be argued, that its mathematical apparatuses contains internal scale and comparison of obtained results of calculation assessment with the scale is performed automatically, which favorably distinguishes the criteria from number of other «internal». In addition, this scale only one reference point, namely value of coefficient η_{eme}, which not associated with legislative normalized parameters and also value of that reference point is different for various types and models of PICE. From number of «universal» criterial apparatuses such attribute has the Harrington desirability function D, but its internal scale is much more flexible and can contain any two reference point for any influencing factor.

Important is the fact that only mathematical apparatus of criteria K_{FE} taking into account PICE fuel consumption, namely in form of middle exploitation value of specific effective mass hourly fuel consumption g_{eme}, as well as directly in form of regime values of mass hourly fuel consumption G_f as the measure of regime values of mass hourly emission of legislative normalized pollutants.

But it was detected that recommended above criterial apparatus is deprived of following opportunities:

– taking into account of legislative established standards or other special values of influencing factors;

– obtaining of regime values (gives only middle exploitation values);

– taking into account of wide specter of such factors.

But PICE fuel consumption in form of middle exploitation values of mass hourly fuel consumption G_{fme} (in kg/h) (has extensive influence) as well as in form of middle exploitation value of specific effective mass hourly fuel consumption g_{eme} (in kg/(kW·h)) (has intensive influence) is ambiguously characterized all aspects of ES of accident-free exploitation process of power plants with PICE. Other things being equal when worded above it is shown in the following.

Lets add and clarify the classification of Types of environmental pollution from PICE as part of PP, presented in article [1] (figure 3), extended to the case of accident-free exploitation process.

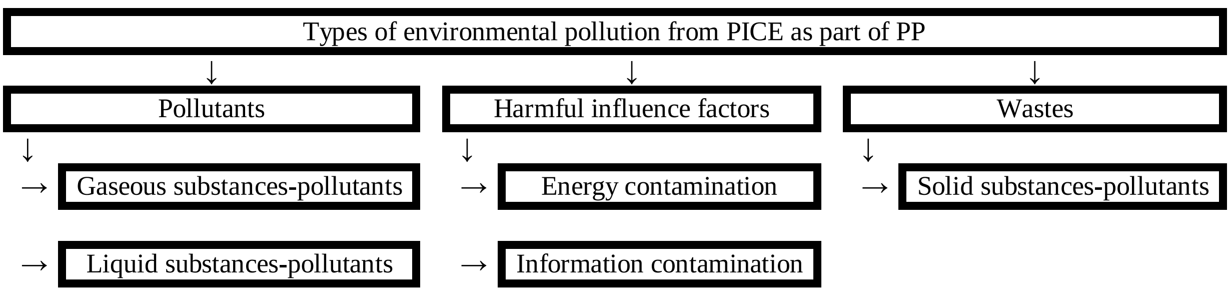

Figure 3 – Classification of Types of environmental pollution from PICE as part of PP [1]

1. Motor fuel of oil origin is non renewable source of energy so the lower the value of G_{fme} and the value of g_{eme} than higher the level of ES of the process in global scale [1, 3].

2. The source of some types of legislative normalized pollutants in EG flow, namely products of uncompleted combustion, namely unburned gaseous hydrocarbons of motor fuel and oil C_nH_m, carbon monoxide CO, particulate matter PM, are exothermal oxidation-reduction reactions of fuel combustion. That's why the more fully they occurs (what means that lower value of G_{fme} and the value of g_{eme}), than higher the level of ES of the process [1, 3, 16, 17].

3. Motor fuel contains atomic and bound sulfur, amount of which is limited by relevance normative documents [18]. That means what mass hourly emission of sulfur oxides SO_x in EG flow also is legislative normalized pollutant albeit indirectly. That's why the lower the value of G_{fme} than lower emission of this pollutant and higher the level of ES of the process [1]. Value of g_{eme} has influence on ratio between SO_x and other sulfur compounds in EG flow shifting the balance aside SO_x.

4. PICE of traditional construction with crankshaft mechanism are powerful sources of noise and vibrations (factors of external imbalance) [1], the intensity of which is higher the greater indicator power produced the PICE during its operation. Both of the ES factors inherently are dissipative processes. That's why the lower the value of G_{fme} and the value of g_{eme} than higher the level of ES of the process.

5. Any PICE is heat machine and all energy that released during combustion process in operation process in one way or another eventually converts into heat energy and transmitted to environment and is a part of its heat pollution [1]. Potentially contained in consumed motor fuel chemical energy can be divided into shortfall (from imperfections of operational process), mechanical loses (from imperfections of PICE construction and necessity of insuring of performance of operational process) and useful (transmitted to the consumer). The consumer spends effective power obtained from PICE for overcoming of dissipative forces (mainly frictional forces) as well during execution of functions assigned to it (mechanical work) as for overcoming of imperfections of they construction. Ratio between the first two and the third components of energetic balance characterized by value of g_{eme}, ratio between the first one and the second one – indicators of toxicity of EG, and also value of G_{fme} characterize of absolute value of heat pollution of environment. However, effective power firstly spent for performance of useful work and only after that inevitable converts into heat. That's why the lower the value of G_{fme} and the value of g_{eme} than higher the level of ES of the process.

6. Motor fuel that exposed to catalytic reforming contains non directly normalized potentially harmful components, namely polycyclic aromatic hydrocarbons (for example, benz(a)piren) and additives with heavy metal compounds (for example, tetraethyl lead, which completely banned by modern normative documents) [4]. Also with mass hourly fuel consumption relates the PICE motor oil consumption for waste with heavy metal compounds. It happens because motor oil falls into combustion chamber of PICE and for some types of PICE it is component of motor fuel, like in PICE with crank-chamber blowdown. That's why the lower the value of G_{fme} and the value of g_{eme} than lower value of mass hourly emission of unburned hydrocarbons in EG flow and accordantly higher the level of ES of the process [1]. The correlation between the value of g_{eme} and the emission of heavy metal compounds and other nonnormable directly harmful components of EG was not detected.

7. Motor fuel and oil contains nitrogen-containing additions which during combustion process with air nitrogen generates nitrogen oxides NO_x, that also are legislative normalized pollutants [1, 3, 16, 17]. The better organized the PICE operation process than higher the temperature in combustion chamber and accordingly higher mass hourly emission of NO_x in EG flow (it value not equal zero even when worsening the PICE operation process). That's why the lower the value of G_{fme} and the higher the value of g_{eme} than higher the level of ES of the process.

8. To the number of products of complete combustion of motor fuel include water H_2O and carbon dioxide CO_2. The second one is product of exothermic oxidation-reduction reactions and presents the greenhouse gas and contributes to global warming on Earth. Emissions of CO_2 by the certain country should not exceed quotas which established by Kyoto Protocol [1, 19]. That's means that CO_2 is legislative normalized pollutant although indirectly. That's why the better and more efficient the fuel burns in combustion chamber, that is the lower the value of G_{fme} and the higher the value of g_{eme} than higher the level of ES of the process.

9. Well-known is that fact that any vehicle with PICE consuming liquid motor fuel pollutes of environment by vapor of that fuel because effects of large and small reservoir breathing. In that way is manifested such type of ES factors as pollution of environment by liquid matters-pollutants [1] during accident-free exploitation process of unit of special purpose technique. The larger value of PICE fuel consumption and the less efficient of its burning than with more larger fuel tank it equips and more often happens full exhaustion of fuel from the tank and accordantly full fuelling of tank what increase the effect of large breathing of reservoir. In the same conditions at large amplitude of changes of daily environmental air temperature also can observes intensification of effect of small breathing of reservoir. That's why the lower the value of G_{fme} and the lower the value of g_{eme} than higher the level of ES of the process.

10. During its operation PICE produced so called carter gases that consists of vapors of motor fuel and oil, fine drops of liquid unburned fuel, air of fresh charge, exhaust gases, which falls in motor oil through gaps between pistons and cylinder liners, drops of liquid motor oil as product of lubrication by spreading process [1]. Carter gases produce an overpressure in internal cavities of PICE carter and pallet and so periodically discharged into environment. From dispersed phase of aerosol of carter gases, namely drops of motor oil fog, they purification caring out by PICE system. Dispersion medium of aerosol of carter gases, namely the mixture of counted above gases, in PICE with no system of neutralization of pollutants in EG flow also not purify from its harmful components. That's why the lower the value of G_{fme} and the lower the value of g_{eme} (in units of PICE which not yet reached the limit condition due to physical wear) than higher the level of ES of the process.

11. Operation of PICE of modern construction controls electronic automatic control systems that consists of source of electric energy (generator and accumulator), sensors, electronic control unit, actuators and wires. Some types of PICE have an ignition system which consists of circuits of high and low voltage. Both of these systems are sources of electromagnetic pollution of environment. That's why the higher the value of G_{fme} than more intensive operates that systems and the lower the value of g_{eme} than with more efficiency they and PICE as a whole operates. That's why the lower the value of G_{fme} and the lower the value of g_{eme} than higher the level of ES of the process.

12. The above systems are powerful sources of informational pollution of environment especially when uses an wireless interfaces for transmitting of data. That's why the lower the value of G_{fme} than more intensive operates that systems and the lower the value of g_{eme} than with more efficiency they and PICE as a whole operates. That's why the lower the value of G_{fme} and the value of g_{eme} than higher the level of ES of the process.

13. The more intensive operates the PICE and more it consumes the motor fuel per unit of time G_{fme} than faster it will run out its physical resource. The more effective it uses consumed fuel g_{eme} than less often it needs for technical maintenance and repair with taking into account that event of failure is random. In case of reaching of limit condition it needs for capital repair or utilization that accompanied by pollution of environment with solid substances-pollutants (wastes), that is parts. That's why the lower the value of G_{fme} and the value of g_{eme} than higher the level of ES of the process.

14. Worded above equally applies to pollution of environment by PICE with liquid substances-pollutants, namely waste technical liquids. That's why the lower the value of G_{fme} and the value of g_{eme} than higher the level of ES of the process.

Presented above considerations about character of correlation between ES factors and influencing on they factors are summarized in table 1.

It should be noted that from number of presented in figure 1 criterial apparatuses only mathematical apparatus of Parsadanov complex fuel and ecological criteria takes into account PICE fuel consumption both in the form of mass hourly G_{fme} and in the form of specific effective mass hourly fuel g_{eme}.

The current version of Road Safety Rules (RSR) of Ukraine [20] in the section 31 «Technical condition of vehicles and they equipment» in paragraph 31.1 defines the following: «The technical condition of vehicles and they equipment should comply with requirements of standards relating to safety of road traffic and protection of environment and also rules of technical exploitation, instructions of manufacturing companies and other normative technical documents». Paragraph 31.4 contain following: «It is prohibited of exploitation of vehicles in accordance with legislation with presents of following technical faults and non-compliance with following requirements» and gives the list of such malfunctions in according subparagraphs. Thus, in subparagraph 31.4.6 «Engine» it is indicated that «a) containing of harmful substances in exhaust gases or its smokiness exceeds the standard established norms; b) leaky fuel system; c) defective exhaust system». Paragraph 31.5 contain following: «In case of occurrence during road driving of malfunctions which are listed in paragraph 31.4 of the Rules the driver must take measures to eliminate them and if this can not be done, then drives as short way as it possible to place of parking or repair. … In case of occurrence during road driving of malfunctions which are listed in paragraph 31.4.7 of the Rules … following driving is prohibited until removing of them …».

That is in RSR concept of «exploitation process of vehicle» has nothing to do with fact of possibility of its independent movement but only in sum with fact of being it in technical condition. Vehicles which due its technical conditions violates the requirements of paragraph 31.4 of RSR and all the more so emergency out of order independently from presents of fact of technical or actually ability of movement does not think so that are in exploitation process.

Also it can be conclude that vehicles which are in condition of technical maintenance or repair also does not think so that are in exploitation process.

Therefore in table 1 presents results of analysis of influence of PICE fuel consumption on values of ES factors only in that part which characterized of non-accident exploitation process.

One of the directions of following studies is qualitative and quantitative gradation of ES factors in its full set, presented in table 1.

Table 1 – Influence of PICE fuel consumption on different components of ES level of accident-free exploitation process of PP (vehicles and technique) of special purpose

№	Ecological safety factor	Influencing factor		
		G_{fme}	g_{eme}	η_{eme}
		kg/h	kg/(kW·h)	–
		Character of correlation*		
1	Consumption of non renewable source of energy	+	+	–
2	Emission of legislative normalized gaseous substances-pollutants, namely products of uncompleted combustion of motor fuel, in aerosol of EG flow (C_nH_m , CO , PM)	+	+	–
3	Emission of indirectly legislative normalized pollutants, namely sulfur oxides in aerosol of EG flow (SO_x)	+	–	+
4	Pollution of environment by noise and vibrations	+	+	–
5	Pollution of environment by heat	+	+	–
6	Emission of PAH and heavy metal compounds in aerosol of EG flow (benz(a)piren, TEL)	+	+	–
7	Emission of legislative normalized gaseous substances-pollutants, namely products of completed combustion of motor fuel, in aerosol of EG flow (NO_x)	+	–	+
8	Emission of indirectly legislative normalized pollutants, namely greenhouse gases, in aerosol of EG flow (CO_2)	+	–	+
9	Emission of vapors of motor fuel and oil due to effects of large and small breathing of fuel reservoirs	+	+	–
10	Emission of aerosol of carter gases	+	+	–
11	Pollution of environment by electromagnetic fields	+	+	–
12	Pollution of environment by information	+	+	–
13	Pollution of environment by solid substances-pollutants (wastes)	+	+	–
14	Pollution of environment by liquid substances-pollutants	+	+	–

*Notation: mark «+» means that increasing of value of influencing factor causing the increasing of value of ES factor; mark «–» – vice versa, causing the decreasing of value of ES factor.

Conclusions. Thus, in present study describes the results of selection of mathematical apparatuses for complex calculated criterial assessment of ES level of exploitation process of PP of special purpose, namely units of fire, emergency and rescue technique with PICE based on analysis of well-known.

Proposed the classification of such mathematical apparatuses which most appropriate for object of assessment by the type of set of initial data into «internal», «external», «recipient» and «universal».

Was made the analysis of advantages and disadvantages of such apparatuses and their application methodics. It was detected that no one of studied criterial apparatuses is not taking into account of full set of ES factors of exploitation process of assessed objects.

Grounded of priority of application of different types of such apparatuses. As the priority recognized «internal» criterial apparatuses.

Grounded of recommendation of application of the most preferable criterial apparatus from the number of priority – Parsadanov complex fuel and ecological criteria as the one that operates with whole set of legislative normalized ES factors, has physical meaning, takes into account the PICE fuel consumption, has internal scale.

Detected the limitations for application of concept «accident-free exploitation process».

Analyzed the influence of PICE fuel consumption on ES factors of accident-free exploitation process of assessed objects.

Detected that recommended criterial apparatus deprived of the opportunity to consider of established norms for accounted factors, obtaining of they regime values and also accounting of more wide specter of ES factors.

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ВИБІР КРИТЕРІАЛЬНОГО АПАРАТУ ДЛЯ КОМПЛЕКСНОГО ОЦІНЮВАННЯ РІВНЯ ЕКОЛОГІЧНОЇ БЕЗПЕКИ ПРОЦЕСУ ЕКСПЛУАТАЦІЇ ЕНЕРГЕТИЧНИХ УСТАНОВОК

У статті описані результати вибору математичного апарату для комплексного розрахункового критеріального оцінювання рівня екологічної безпеки процесу експлуатації енергетичних установок, оснащених поршневим двигуном внутрішнього згоряння, на основі аналізу відомих. Запропоновано класифікацію таких математичних апаратів, найбільш придатних для об'єкта оцінювання, за видом набору використовуваних вихідних даних. Проведено аналіз переваг і недоліків таких апаратів та методик їх застосування. Обґрунтовано пріоритетність використання типів таких апаратів. Обґрунтована рекомендація щодо використання комплексного паливно-екологічного критерію проф. Парсаданова як єдиного, який оперує повним набором законодавчо нормованих факторів екологічної безпеки, має фізичний зміст і враховує витрати палива двигуном. Визначено обмеження на застосування поняття «безаварійна експлуатація». Проаналізовано вплив витрати палива двигуном на фактори екологічної безпеки процесу безаварійної експлуатації оцінюваних об'єктів. Виявлено, що рекомендований критеріальний апарат позбавлений можливості враховувати встановлені нормативи факторів, що враховуються, отримання їх порежімних значень, а також врахування їх більш широкого спектра.

Ключові слова: техногенно-екологічна безпека, комплексне критеріальне оцінювання, енергетична установка, двигун.

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ВЫБОР КРИТЕРИАЛЬНОГО АППАРАТА ДЛЯ КОМПЛЕКСНОГО ОЦЕНИВАНИЯ УРОВНЯ ЭКОЛОГИЧЕСКОЙ БЕЗОПАСНОСТИ ПРОЦЕССА ЭКСПЛУАТАЦИИ ЭНЕРГЕТИЧЕСКИХ УСТАНОВОК

В статье описаны результаты выбора математического аппарата для комплексного расчетного критериального оценивания уровня экологической безопасности процесса эксплуатации энергетических установок, оснащенных поршневым двигателем внутреннего сгорания, на основе анализа известных. Предложена классификация таких математических аппаратов, наиболее подходящих для объекта оценивания, по виду набора используемых исходных данных. Проведен анализ преимуществ и недостатков таких аппаратов и методик их применения. Обоснована приоритетность использования типов таких аппаратов. Обоснована рекомендация по использованию комплексного топливно-экологического критерия проф. Парсаданова как единственного, который оперирует полным набором законодательно нормированных факторов экологической безопасности, имеет физический смысл и учитывает расход топлива двигателем. Определены ограничения на применение понятия «безаварийная эксплуатация». Проанализировано влияние расхода топлива двигателем на факторы экологической безопасности процесса безаварийной эксплуатации оцениваемых объектов. Выявлено, что рекомендуемый критериальный аппарат лишен возможности учитывать установленные нормативы учитываемых факторов, получать их порежимные значения, а также учета их более широкого спектра.

Ключевые слова: техногенно-экологическая безопасность, комплексное критериальное оценивание, энергетическая установка, двигатель.