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Internal Combustion Engines

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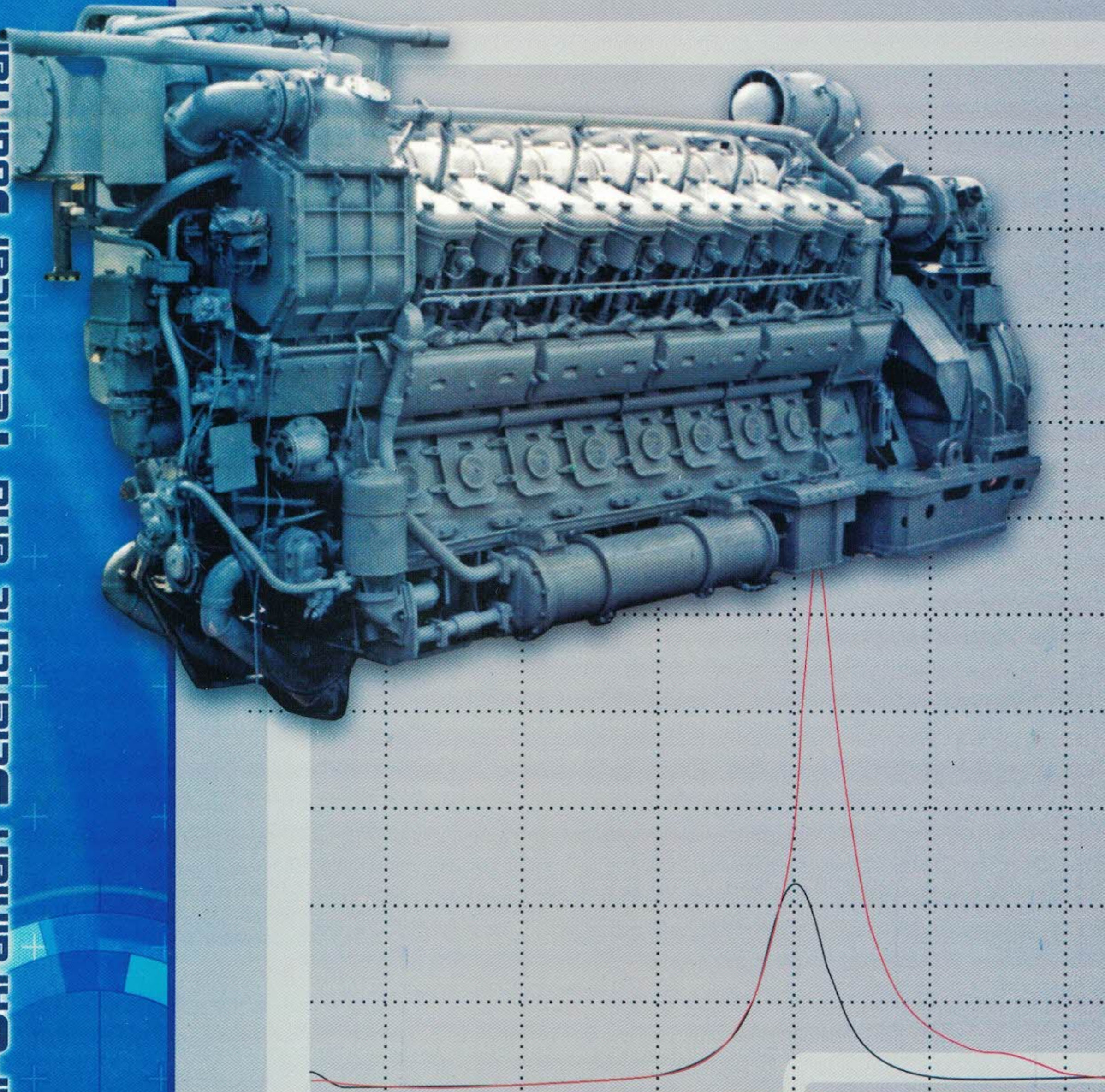

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INTERNAL COMBUSTION ENGINES

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АДРЕСА РЕДКОЛЕГІЇ
61002, м. Харків, вул. Кирпичова, 2, НТУ «ХПІ», кафедра ДВЗ
Тел. (057) 707-60-89, 707-68-48,
E-mail: rykova@kpi.kharkov.ua, dvs@kpi.kharkov.ua
Офіційний сайт видання: http://dvs.khpi.edu.ua/

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Всеукраїнський науково-технічний журнал з питань теорії і практики, моделювання та експериментальних досліджень робочих процесів, конструкцій, інноваційних технологій, виготовлення і експлуатації двигунів внутрішнього згоряння. Матеріали статей були рекомендовані Програмним комітетом XXVI Міжнародного конгресу двигунобудівників до відкритої публікації в журналі і прийняті редакційною колегією.

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O. M. Kondratenko, V. A. Andronov, V. Yu. Koloskov, O. O. Tkachenko, Ye. V. Kapinos

DETERMINATION OF REFERENCE VALUES OF COMPLEX FUEL AND ECOLOGICAL CRITERION AS THE SEPARATE INDEPENDENT FACTOR OF ECOLOGICAL SAFETY

In this study the approach and method on its basis for calculated assessment of reference values of complex fuel-ecological criterion of Prof. I. Parsadanov as separate independent ecological safety factor and as reference points of psychophysical scale of the partial desirability function when using it as the ecological safety factor of power plants with reciprocating internal combustion engines exploitation process was proposed. Also in the study calculated assessment of reference values of ecological indicators of reciprocating internal combustion engines as components of complex fuel-ecological criterion depending on magnitudes of effective power and coordinates of field of engine operating regimes for different levels of statutory ecological standards in force in Ukraine and previously in force was carried out. Thus, calculated assessment of reference values of complex fuel-ecological criterion and its components was performed and obtained the distribution of such reference values in field of 2Ch10.5/12 autotractor diesel engine operating regimes depending as well as dependences of such reference values on magnitudes of level of ecological standards EURO, engine effective performance and lower calorific value of engine fuel. So, the study for the first time proposes the approach to calculated assessment of reference values of the complex fuel-ecological criterion of Prof. I. Parsadanov as reference points of the psychophysical scale of the Harrington's partial desirability function when using it as the separate independent ecological safety factor of exploitation process of power plants with reciprocating ICE. The method, based on the proposed approach for calculative evaluation of reference values of the complex fuel-ecological criterion of Prof. I. Parsadanov as reference points of psychophysical scale of partial desirability function is suitable for obtaining necessary data for the complex criterion evaluation of the ecological safety level of operation process of power units with piston ICE using generalized Harrington desirability function, in the structure of which the complex fuel-ecological criterion acts as a distinct factor of environmental safety.
Key words: *environment protection technologies; ecological safety; power plants; internal combustion engines; reference values; criteria-based assessment; EURO level.*

Relevance of the study and problem statement

The relevance of the research presented in this study is due to the following. In the monograph [1] the analysis of 9 known mathematical apparatuses suitable for the implementation of complex calculated assessment of the level of ecological safety (ES) of the process of accident-free exploitation of power plants (PP) with reciprocating internal combustion engine (RICE). According to the results of analysis and systematization in the form of the corresponding classification it is established that the most suitable for achievement of the formulated purpose it is possible to accept the mathematical apparatus of complex fuel-ecological criterion of Prof. I. Parsadanov (NTU “KhPI”) K_{fe} (described in the monograph [2]) and the Harrington generalized desirability function D (described in the work [3]). In the same source, a comparative analysis of the advantages and disadvantages of selected alternative criterion mathematical apparatuses is carried out and it is concluded that it is rational for further research to use both apparatuses with mutual strengthening of their advantages and weakening of disadvantages.

The first step in this way is to use the mathematical apparatus of the generalized desirability function with the structure of the considered influencing factors, identical to the complex fuel-ecological criterion. Since the main advantage of the K_{fe} criterion is taking into account the mass hourly fuel consumption of RICE G_{fuel}, then to use this advantage it is necessary to determine the ponderability of this ES factor in comparison with others – emissions of legislatively regulated pollutants with exhaust gas (EG) flow G(k), which is done in the monograph [1], that also provides the improved classification of ES factors, the source of which is RICE in PP, which consists of 15 points, and also reveals the nature of the influence of the value G_{fuel} for all other ES factors in the specified classification. Therefore, given that the fuel component of the K_{fe} criterion completely determines its ecological component, as established in the monograph [1], it is rational to explore the features of the application of another approach, namely the use of the K_{fe} criterion as a separate independent influencing factor in the structure of the generalized desirability function D. At the same time it becomes possible to consider indicators of vibration (degree of non-uniformity of rotation of crankshaft δ_{cs}, Klimov-Stechkin criteria ξ_{cs} and η_{cs}), noise (equivalent L_{Aequ} and maximum $L_{A\max}$ noise level), thermal pollution (mass hourly fuel consumption G_{fuel} separately from the fuel component of the criterion K_{fe}), emissions of sulfur oxides $G(SO_x)$, etc.

To implement this approach, it is necessary to have data on the magnitudes of such ES factor (i.e. the response of the local quality criterion r), which can be correlated with the reference points of the psychophysical scale of desirability of magnitudes of the response r “good” and “bad”, and their corresponding magnitudes of the scale of values of basic assessment of the magnitudes of the partial desirability function d = =0.63…0.80 and d = 0.2…0.32. Thus for reference values of indicators of ecological component of K_{fe} criterion it is proposed to choose the emission magnitudes of legislatively normalized pollutants contained in the relevant standards (for example in [4,5]), for the current (mark of "good" and d = 0.80) and previous (mark "bad" and d = 0.20) levels of EURO.

However, different units of RICE, which are currently in operation, belong to different generations of such equipment and are in different current technical condition (corresponding to the degree of physical wear and compliance with the order of routine maintenance and repair) and therefore are characterized by different levels of fuel efficiency, i.e. the magnitude of RICE specific effective mass hourly fuel consumption g_e. Therefore it is necessary to receive dependences of magnitude of K_{fe} criterion, in the structure of which the indicators of ecological component acquire legislatively established magnitudes, from the magnitude of fuel component of the criterion for different levels of EURO standards. However, when analyzing the scientific and technical literature, authors did not find the results of such a study, so obtaining the set of magnitudes of the K_{fe} criterion, which can be correlated with the reference points of the scale of the partial desirability function d, is a topical scientific and technical challenge with signs of scientific novelty and practical value.

It should be noted that RICE is a powerful source of environmental pollution by various physical factors, including non-renewable energy sources (engine fuel of petroleum origin) – this is a qualitative aspect of the relevance of topic of this study, they together produce up to 75 % of energy (mechanical and electrical) in our country [2] – this is a quantitative aspect of the relevance of topic of this study.

Purpose of the study is to determine the reference values of the complex fuel-ecological criterion of Prof. I. Parsadanov as the separate independent ES factor and as reference points of the psychophysical scale of the partial desirability function. **The task of the study** is to determine the necessary characteristics of the complex fuel-ecological criterion as the separate independent ES factor and as partial desirability functions for a complex assessment of the ES level exploitation process of PP with RICE based on the mathematical apparatus of the Harrington generalized desirability function. **Object of the study** is the quantitative characteristics of the fuel-ecological criterion as the separate independent ES factor. **Subject of the study** are the magnitudes of the reference values of the fuel-ecological criterion as a separate independent ES factor for different levels of legislatively established ecological standards and depending these magnitudes on the level of RICE fuel efficiency and other influencing factors. **Methods of the study.** Analysis of specialized scientific and technical, normative, patent and reference literature [1–22], analysis of data of engine bench tests on standardized steady test cycles, basics of the scientific discipline "Theory of RICE" [7–10], improved mathematical apparatus of complex fuel-ecological criterion, method of least squares.

Tasks of the study are the following points. 1. Development of the method of calculated assessment of reference values of the complex fuel-ecological criterion as reference points of the psychophysical scale of the partial desirability function when using it as the separate independent ES factor of operation process of PP with RICE. 2. Calculated assessment of reference values of RICE ecological performance indicators as components of complex fuel-ecological criterion. 3. Calculated assessment of reference values of complex fuel-ecological criterion and analysis of its results.

The study was performed on the example of autotractor diesel engine D21A1 (2Ch10.5/12 in accordance with ISO 3046-1:2002), whose technical description is given in the source [6], and the standardized steady testing cycle ESC (in accordance with UENCE Regulations № 49 [4]).

Scientific novelty of the obtained results is as follows. For the first time the approach to calculated assessment of reference values of the complex fuel-ecological criterion of Prof. I. Parsadanov as reference points of the psychophysical scale of the Harrington's partial desirability function when using it as the separate independent ES factor of operation process of PP with RICE was proposed.

Practical value of the obtained results. The method based on the proposed approach for the calculated assessment of reference values of the complex fuel-ecological criterion as reference points of the psychophysical scale of the partial desirability function suitable for obtaining the necessary data for the implementation of a complex criteria-based assessment of the ES level of operation process of PP with RICE using the Harrington`s generalized desirability function, in the structure of which there is a complex fuel-ecological criterion as the separate independent ES factor.

1. Method of calculation evaluation of reference values of complex fuel-ecological criterion as the separate independent ES factor

The mathematical apparatus of Harrington`s generalized desirability function D, which is related to fuzzy logic, is presented in the sources [1, 3]. This function, in its idea, is a quantitative, unambiguous, unique and universal indicator of the quality of the object under study, and is also characterized by adequacy and statistical sensitivity. The magnitude of generalized desirability function D for the i-th representative operating regime of RICE in the model of its operation, in the structure of which as separate independent influencing ES factor there is complex fuel-ecological criterion K_{fe}, determined by the formula (1).

$$D_i = \sqrt[\sum_{k=1}^{n} \upsilon_k]{\prod_{k=1}^{n} d_{ki}^{\upsilon_k}} = \sqrt[(\upsilon_{k_1}+\upsilon_{k_2}+\ldots+\upsilon_{k_n})]{d_i(k_1)^{\upsilon_{k_1}} \cdot d_i(k_2)^{\upsilon_{k_2}} \cdot \ldots \cdot d_i(k_n)^{\upsilon_{k_n}}}, \quad (1)$$

where d_k – partial desirability function that meets the k-th quality criterion, $d_k = 0\ldots1.0$, and $k_1 = K_{fe}$; n – number of quality criteria considered; υ_k – weight factor of the k-th quality criterion considered, $0 < \upsilon_k \le 1$, and υ_{k1} = 38.4 + 245.3 = 283.7 (see source [1]).

The mathematical apparatus of this function provides transformation of magnitudes of responses of local criteria of quality r_k in the dimensionless scale of desirability – magnitudes of partial desirability functions d_k – according to the table of base mark of desirability scale, that is Table 1, which also contains a psychophysical scale [3].

Table 1. Base marks of the scale of real desirability d_k [3]

Mark of desirability of the response magnitude r_{ki}	Quantitative magnitude according to the desirability scale d_{ki}
Very good	1.0 … 0.8
Good	0.8 … 0.63
Satisfactory	0.63 … 0.37
Bad	0.37 … 0.2
Very bad	0.2 … 0.0

In this study as partial functions of desirability d_k or those that meet, firstly, the fuel-ecological criterion K_{fe} (marked with index k_1 in the formula (1)), and secondly, the values that could potentially be indicators of other ES factors, included in the improved classification in the source [1], which, however, are not taken into account by the mathematical apparatus of the K_{fe} criterion (that is, all but the mass hourly emissions of legislatively normalized pollutants – G(PM), $G(NO_x)$, G(CO), $G(C_nH_m)$, as well as indirectly – the mass hourly fuel consumption of diesel engine G_{fuel}), namely indicators of noise (equivalent L_{Aequ} and maximum $L_{A\max}$ noise level), vibration (the degree of uneven rotation of the crankshaft δ_{cs}, Klimov-Stechkin criteria ξ_{cs} and η_{cs}), thermal pollution (mass hourly fuel consumption G_{fuel}), emissions of sulfur oxides $G(SO_x)$ etc (indicated by indexes $k_2 \ldots k_n$ in the formula (1)). ES factor in the structure of the desirability function D, criterion K_{fe} is chosen as the main one, is a case of a real one-sided constraint and is described by the formula (2).

$$d_{ki} = \exp[-\exp(a_{ki} + b_{ki} \cdot r_{ki})]; \quad k = \{K_{fe}, G_{SO_x}, \delta_{cs}, \xi_{cs}, \eta_{cs}, L_{Aequ}, L_{A\max}, \ldots\}, \quad (2)$$

where r_{ki} –actual magnitude of k-th quality criterion on the i-th representative regime of RICE operation in the model of its operation; a_{ki} and b_{ki} – coefficients determined on the basis of establishing correspondence between a pair of characteristic magnitudes r_{ki} and d_{ki} according to Table 1.

Data that allows to determine the parameters of compounds of formulas (2) for the partial desirability functions d_k are obtained by solving of system of two equations (see formulas (3) – (5)) for cases that put in accordance with one characteristic magnitudes r_{ki} and d_{ki}, known from practice or normative documents.

$$\begin{cases} d_{kidn} = \exp[-\exp(a_{ki} + b_{ki} \cdot r_{kidn})] \\ d_{kiup} = \exp[-\exp(a_{ki} + b_{ki} \cdot r_{kiup})] \end{cases}; \quad (3)$$

$$a_k = \frac{\ln(-\ln(d_{kup})) \cdot r_{kdn} - \ln(-\ln(d_{kdn})) \cdot r_{kup}}{r_{kdn} - r_{kup}}, \quad (4)$$

$$b_k = \frac{\ln(-\ln(d_{kdn})) - \ln(-\ln(d_{kup}))}{r_{kdn} - r_{kup}}, \quad (5)$$

where indices up and dn marked characteristic magnitudes of r_{ki} and d_{ki}, corresponding to the assessed marks on psychophysical scale "good" (i.e. d_{kiup} = 0.63 …0,80) and "bad" (i.e. d_{kidn} = 0.20…0.32) taking into account the specific features of the quantities r_{ki}.

The essence of the proposed method is that as magnitudes of r_{kiup} will be used the individual regime magnitudes of the K_{fe} criterion (see formula (6)), the factors of the ecological component of which (G(PM), $G(NO_x)$, G(CO), $G(C_nH_m)$) meet current legal standards (i.e. the level of EURO VI, the most stringent in terms of historical retrospect), and as magnitudes of r_{kidn} – value of the K_{fe} criterion, the factors of ecological component of which correspond to less rigid in terms of historical retrospect standards (i.e. levels of EURO I…VI). Such requirements in historical retrospect are summarized in Table 2.

$$K_{fei} = \frac{3600 \cdot N_{ei}}{H_u \cdot G_{fueli}} \cdot \frac{1000 \cdot G_{fueli}}{G_{fueli} + \sigma \cdot f \cdot \sum_{k=1}^{h} (A(k) \cdot G(k)_i)}, ‰. \quad (6)$$

In standards of toxicity indicators of EG of RICE [4,5] the maximum permissible magnitudes of specific effective mass hourly emissions of pollutants with EG flow are specified (g(PM), $g(NO_x)$, g(CO), $g(C_nH_m)$ in kg/(kW·h)), rather than the value of their mass hourly emission (G(PM), $G(NO_x)$, G(CO), $G(C_nH_m)$ in kg/h), which appear in the formula to determine the magnitude of the K_{fe} criterion. Such magnitudes are correlated by formula (7), i.e. the magnitude of mass hourly emission of k-th pollutant G(k), corresponding to the normatively established magnitude of the specific effective mass hourly emission of the same pollutant g(k), depend on the magnitude of RICE effective power N_e in kW, and therefore from the coordinates of the field of its operating regimes (crankshaft speed n_{cs} in rpm and torque $M_{кр}$ in N·m) which is reflected in the formula (8).

Table 2. Diesel engine toxicity indicators [1, 2, 4, 5, 7–10]

EURO level	Year of introduction	Specific effective mass hourly emission g_k, g/(kW·h)			
		PM	NO_x	C_nH_m	CO
I	1992	0.612	8.0	1.1	4.5
II	1996	0.25…0.15	7.0	1.1	4.0
III	2000	0.10	5.0	0.66	2.1
IV	2005	0.02	3.5	0.46	1.5
V	2008	0.02	2.0	0.25	1.5
VI	2012	0.01	0.5	0.2	1.0

$$G_k = g_k \cdot N_e \text{, kg/h;} \qquad (7)$$

$$N_e = n_{кв} \cdot M_{кр} / 9550 \text{, kW.} \qquad (8)$$

2. Obtaining of reference values of indicators of ecological performance of RICE

Dependencies of magnitudes of reference values of emission G(PM), $G(NO_x)$, G(CO), $G(C_nH_m)$, total emission $\Sigma(G(k))$ and totel reduced $\Sigma(A(k) \cdot G(k))$ and from magnitudes of effective power N_e, described by formula (7) according to Table 2, for different levels of EURO are illustrated in the form of graphs in Fig. 1. Distribution of magnitudes of power N_e, described by formula (8), in the field of operation regimes of diesel engine 2Ch10.5/12 is shown in Fig. 2. Distribution of magnitudes of reference values of emission G(PM), $G(NO_x)$, G(CO), $G(C_nH_m)$ and $\Sigma(A(k) \cdot G(k))$ on the field of operating regimes of that diesel engine for extreme levels EURO I and VI is illustrated in Fig. 3 and 4.

Fig. 1 shows that such dependences for any RICE are linear, the emission reference values increase with increasing magnitude of effective power. So with increasing magnitude of N_e from 0.05 to 25 kW: a) value G_n(PM) increase from 0.03 to 15.3 g/h for EURO I and from 0.001 to 0.25 g/h for EURO VI; b) value $G_n(NO_x)$ – from 0.4 to 200 g/h (EURO I) and from 0.025 to 12.5 g/h (EURO VI); c) value $G_n(C_nH_m)$ – from 0.055 for 27.5 g/h (EURO I) and from 0.01 to 5.0 g/h (EURO VI); d) value G_n(CO) – from 0.023 to 112.5 g/h (EURO I) and from 0.05 to 25.0 g/h (EURO VI); e) value $\Sigma(A(k) \cdot G(k))_n$ – from 23.0 to 11480.5 g/h (EURO I) and from 1.2 to 604.8 g/h (EURO VI); f) value $\Sigma(G(k))_n$ – from 0.71 to 355.3 g/h (EURO I) and from 0.09 to 24.8 g/h (EURO VI).

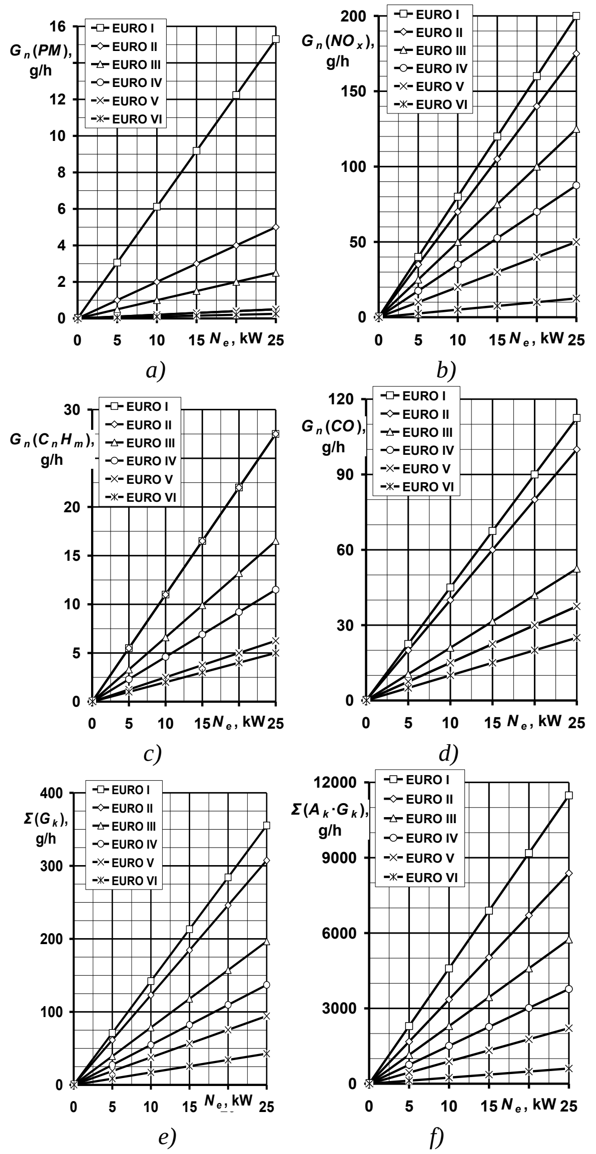


Fig. 1. Dependences of magnitudes of reference values of magnitudes of mass hours of emissions G(PM), $G(NO_x)$, G(CO), $G(C_nH_m)$ (a – d) and reference values of mass emission hour magnitudes Σ(A(k)·G(k)) and Σ(G(k)) (e, f) from the magnitudes of RICE effective power N_e for different levels EURO

Fig. 2–4 shows that such distributions for diesel engine 2Ch10.5/12 have the form of planes inclined to the axes of both coordinates of the field of operation regimes of the engine: a) value G_n(PM) varies from 0.001 (EURO VI) and 0.029 (EURO I) (at $n_{кв}$ = 800 rpm and $M_{кр}$ = 0,56 N·m – regime A) to 0.207 (EURO VI) and 12.7 (EURO I) g/h (at $n_{кв}$ = 1800 rpm i $M_{кр}$ = = 110 N·m – regime B); b) value $G_n(NO_x)$ – from 0.023 (EURO VI) and 0.38 (EURO I) (regime A) to 10.4 (EURO VI) and 165.9 (EURO I) g/h (regime B);

c) value $G_n(C_nH_m)$ – from 0.009 (EURO VI) and 0.052 (EURO I) (regime A) to 4.1 (EURO VI) and 22.8 (EURO I) g/h (regime B); d) value G_n(CO) – from 0.047 (EURO VI) and 0.211 (EURO I) (regime A) to 20.7 (EURO VI) and 93.3 (EURO I) g/h (regime B); e) value $\Sigma(A(k)\cdot G(k))_n$ – from 1.0 (EURO VI) and 2.2 (EURO I) (regime A) to 502 (EURO VI) and 9521 (EURO I) g/h (regime B).

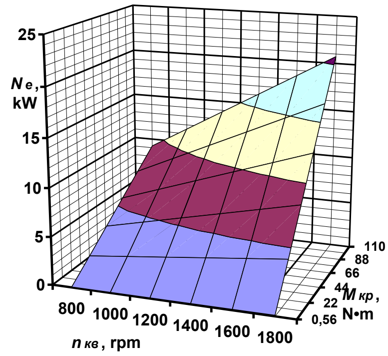


Fig. 2. Distribution of magnitudes of effective power N_e on field of operating regimes of diesel engine 2Ch10.5/12

3. Results of calculated assessment of reference values of complex fuel-ecological criterion and their analysis

For the study formula (6) was converted to the form of formula (9).

$$K_{fei} = \frac{3600 \cdot N_{ei}}{H_u \cdot \left(G_{fueli} + \sigma \cdot f \cdot N_{ei} \cdot \sum_{k=1}^{h} (A_k \cdot g_{ki}) \right)} =$$

$$= \left| \begin{array}{l} U = 3600 / H_u = const; \\ V = \sigma \cdot f \cdot \sum_{k=1}^{h} (A_k \cdot g_{ki}) = f(EURO) \end{array} \right| =$$

$$= \frac{U \cdot N_{ei}}{G_{fueli} + V \cdot N_{ei}} = \frac{U \cdot N_{ei}}{g_{ei} \cdot N_{ei} + V \cdot N_{ei}} = \quad , ‰ \quad (9)$$

$$= \frac{U}{g_{ei} + V} = f(g_{ei}; EURO)$$

where U = 84.3 kg/(kW·h) – constant value; V – substitution that is constant for a certain level EURO, kg/(kW·h).

Entered values U and V have the following physical meaning: U – magnitude of the specific effective mass hourly fuel consumption of diesel engine, provided that its effective efficiency coefficient η_e is equal to 1.0; V – magnitude of the specific reduced effective mass hourly emission of full set of legislatively standardized pollutants under certain conditions of RICE operation. Reference values of V and values of its relative change δV for different EURO levels for basic values σ = 1.0 and f = 1.0 and H_u = 42.7 MJ/kg is illustrated in Fig. 5 in the form of a histogram. Value of U for different types of motor fuel, i.e. the value H_u, and for basic values σ = 1.0 i f = 1.0 illustrated in Fig. 4 in the form of a graph. Fig. 3 shows that the reference magnitudes of value V with increasing EURO (increasing the stringency of ecological requirements for RICE) decreases, for EURO VI by 95 % compared to EURO I.

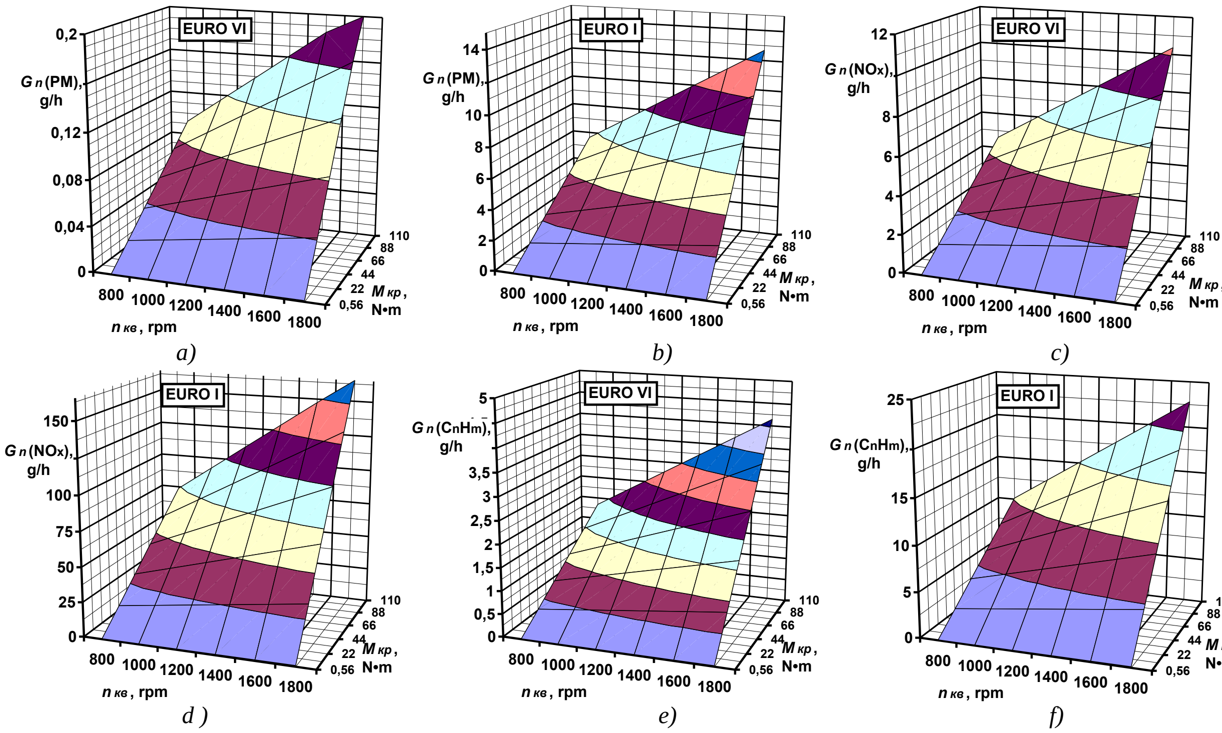


Fig. 3. Distribution of reference values of emissions $G_n(PM)$ (a, b), $G_n(NO_x)$ (c, d) and $G_n(C_nH_m)$ (e, f) on the field of operating regimes of 2Ch10.5/12 diesel engine for extreme levels EURO I and VI

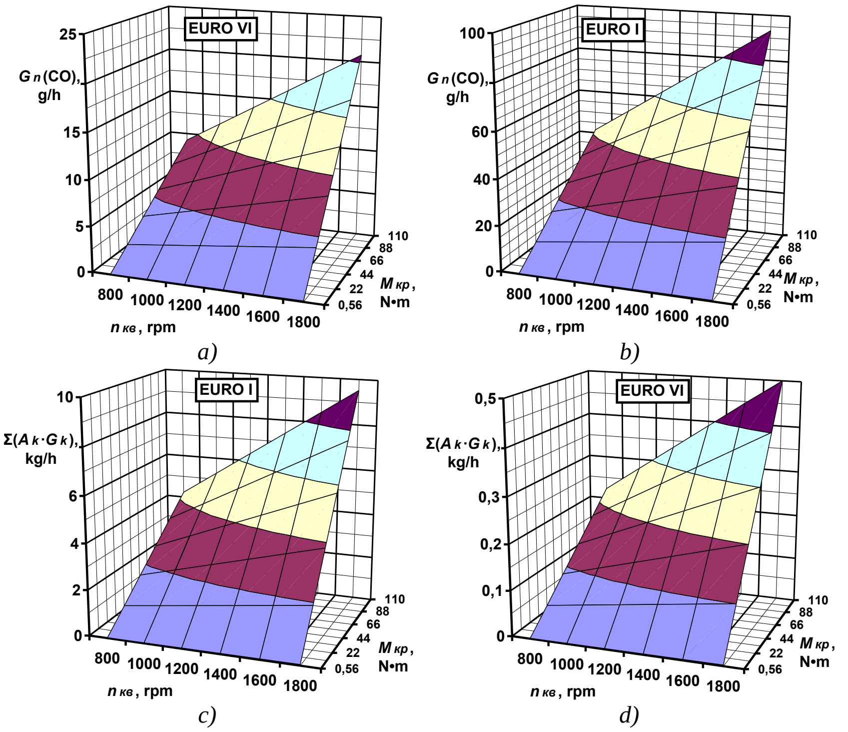


Fig. 4. Distribution of reference values of emission $G_n(CO)$ (a, b) and $\Sigma(A(k)\cdot G(k))_n$ (c, d) on the field of operating regimes of 2Ch10.5/12 diesel engine for extreme levels EURO I and VI

Reference values of specific effective mass hourly fuel consumption of RICE g_e for different types of engine fuel (with different magnitudes of calorific value H_u in MJ/kg) depend on the value of engine effective efficiency coefficient η_e. Such dependences are illustrated in Fig. 6. Fig. 6 shows that such dependences have the form of family of hyperbolas, magnitude g_e while varying from 1440 (η_e = 0.1, H_u = 25 MJ/kg) до 28.8 g/(kW·h) (η_e = 1.0, H_u = 125 MJ/kg).

Fig. 6 shows that the reference values of the value U with increasing of value H_u decrease according to the hyperbolic law and in the full range of changes of the influencing factor (from 25 to 125 MJ/kg) change on ±70 % compared to the basic value H_u = 42.7 MJ/kg, which is equal to 84.5 g/(kW·h).

Fig. 8 shows graphs of the dependence of the reference values of the value g_e from the value of effective performance coefficient η_e for different types of engine fuel and for basic values σ = 1.0 and f = 1.0. Fig. 8 shows that such values g_e fall according to the hyperbolic law of increasing value η_e. At value of η_e = = 0.5, which reflects the objective limit of RICE modern possibilities, for conventional diesel fuel (H_u = 42.7 MJ/kg) value g_e = 168.6 g/(kW·h), when decreasing η_e to 0.1 it grows by 400 %, and with growth of η_e to 1.0 – decreases by 50 %.

Dependence of reference values of the K_{fe} criterion from the magnitudes of RICE specific effective mass hourly fuel consumption g_e for different EURO levels and basic values σ = 1.0, f = 1.0 and H_u = 42.7 MJ/kg, described by formula (9), is shown in Fig. 9. Actually graphs in Fig. 9 are the basis for obtaining the desired values of the reference points of the corresponding partial desirability scale.

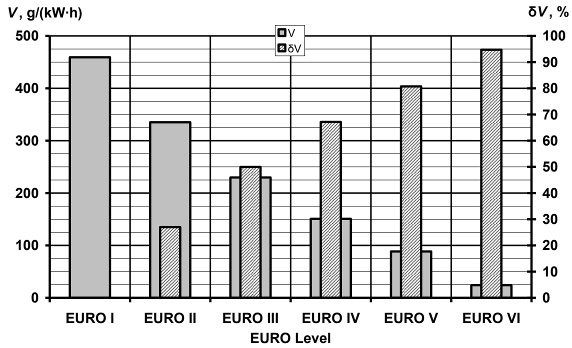


Fig. 5. Magnitudes of values V and δV for different EURO levels for basic values σ = 1.0 і f = 1.0 and H_u = 42.7 MJ/kg

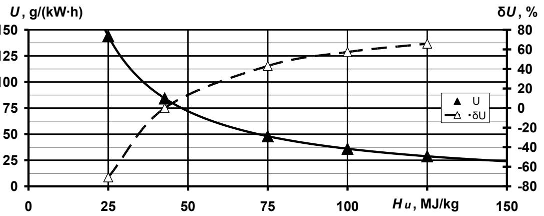


Fig. 6. Magnitudes of U and δU for different types of engine fuel and for basic values σ = 1.0 and f = 1.0

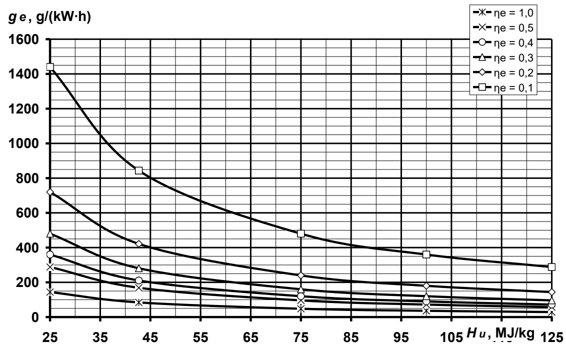


Fig. 7. Graphs of dependences of the magnitudes of value g_e from the magnitudes of value H_u for different constant magnitudes η_e

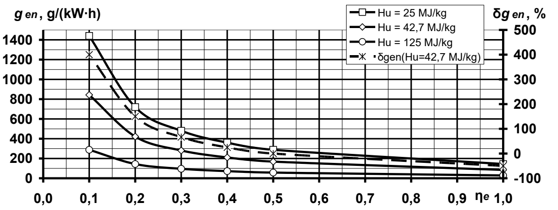
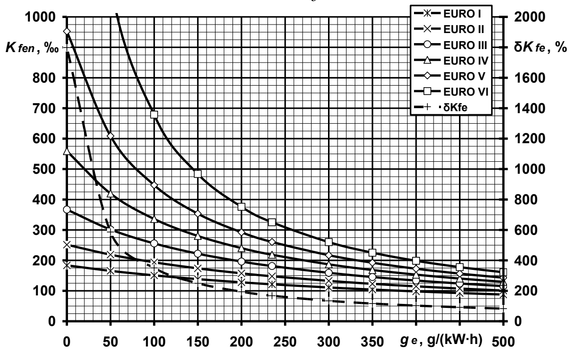
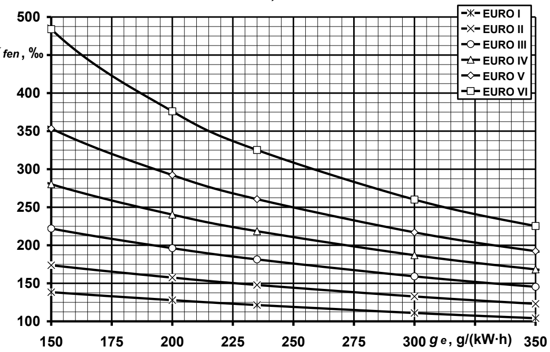


Fig. 8. Dependences of reference values g_e from the magnitudes of effective performance coefficient η_e for different types of engine fuel and for basic values σ = 1.0 and f = 1.0



a)



b)

Fig. 9. Graphs of dependences of reference values of K_{fe} criterion from the magnitude of RICE specific effective mass hourly fuel consumption g_e for different EURO levels and basic values σ = 1.0, f = 1.0 and H_u = 42.7 MJ/kg

They are constructed within the widest of theoretically possible limits of change of magnitudes g_e – from 0 to 500 g/(kW·h) and the K_{fe} criterion itself – from 0 to 1000 ‰. The real limits of change in these magnitudes are as follows: g_e – from 150 to 350 g/(kW·h) (see Fig. 6), K_{fe} – from 100 to 500 ‰ (see Fig. 8). Such graphs, constructed within the specified real limits of change of coordinates are given in Fig. 9,b. Fig. 9 shows that the graphs depicted on it are the family of hyperbolas, the reference values of the K_{fe} criterion decrease with increasing magnitude g_e, and the difference between such values for the extreme values of the EURO level decreases from 1800 (at g_e = 0 g/(kW·h)) to 83 % (at g_e = 500 g/(kW·h)).

It is known that the physical meaning of the K_{fe} criterion is that it is effective performance coefficient of RICE taking into account its legislatively regulated EG ecological indicators. Thus, its limit values for any stationary engine mode are the values of the effective performance η_e. These are the values it achieves when it is perfectly environmentally friendly, i.e. when there are no legally regulated pollutants in its EG stream. Distribution of magnitudes of η_e for 2Ch10.5/12 diesel engine in the field of its operating regimes are shown in Fig. 3.6. Fig. 3.6 shows that the magnitudes of η_e are distributed on a field of operating regimes of that diesel engine unevenly and acquire magnitudes within 0.08 (regime A) to 0.356 (regime B).

Distribution of reference values of K_{fe} criterion on field of operating regimes of 2Ch10.5/12 diesel engine for extreme levels of EURO – I and VI, and basic values σ = 1.0, f = 1.0 and H_u = 42.7 MJ/kg shown in Fig. 11.

Fig. 11 shows that such reference values of the K_{fe} criterion distributed over the field of operating regimes unevenly and reach maximum 61 and 200 ‰ respectively for EURO I and EURO VI on various steady regimes of RICE operation. The nature of the distribution differs significantly for different EURO levels. This difference is due to the peculiarities of the distribution of magnitude of η_e of this diesel engine and reference values of pollutant emissions in this field, presented in Fig. 2–4.

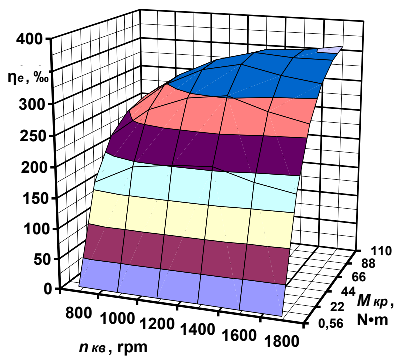


Fig. 10. Distribution of magnitudes of η_e on the field of operating regimes of 2Ch10.5/12 diesel engine

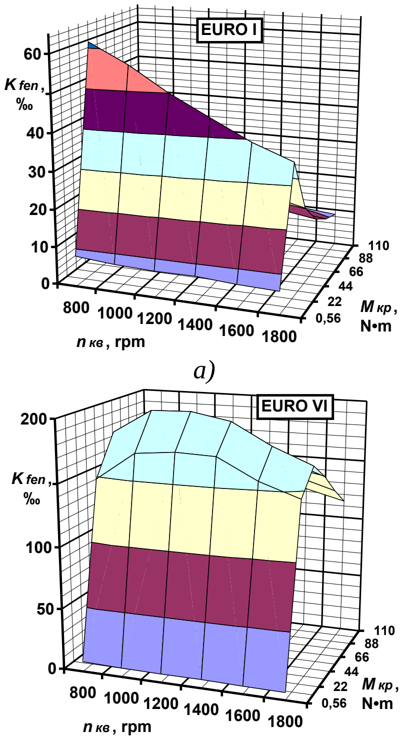


Fig. 11. Distribution of reference values of K_{fe} criterion on the field of operating regimes of 2Ch10.5/12 diesel engine for extreme levels EURO I and VI

The results of calculations of the reference values of the K_{fe} criterion averaged over the field of operation regimes of the autotractor diesel engine 2Ch10.5/12 for all EURO levels are shown in Fig. 11, the dependence graph on it is described by the method of least squares in the form of a 4-degree polynomial – this is formula (10).

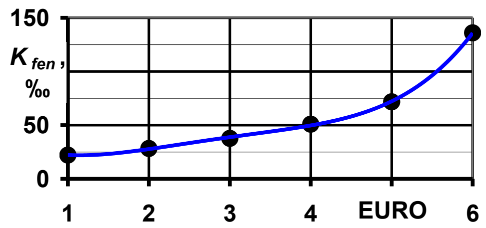


Fig. 12. Graph of dependences of reference values of the K_{fe} criterion averaged over the field of operation regimes of the autotractor diesel engine 2Ch10.5/12 for all EURO levels

$$K_{fen} = 0.735 \cdot EURO^4 - 8.325 \cdot EURO^3 + 34.366 \cdot EURO^2 - 50.346 \cdot EURO + 45.783, ‰. \quad (10)$$

Conclusions

Thus, based on the analysis of the results of the study described in this paper, the following conclusions can be drawn.

1. Approach and method on its basis for calculated assessment of reference values of complex fuel-ecological criterion of Prof. I. Parsadanov as separate independent ES factor and as reference points of psychophysical scale of the partial desirability function when using it as the ES factor of PP with RICE operation process was proposed.

2. Calculated assessment of reference values of ecological indicators of RICE as components of complex fuel-ecological criterion depending on magnitudes of effective power and coordinates of field of engine operating regimes for different levels of legislative ecological standards in force in Ukraine and previously in force was carried out.

3. Calculated assessment of reference values of complex fuel-ecological criterion and its components was performed and obtained the distribution of such reference values in field of 2Ch10.5/12 diesel engine operating regimes depending as well as dependences of such reference values on magnitudes of level of ecological standards EURO, effective performance coefficient of engine and lower calorific value of engine fuel.

Identified dependences are described by formulas by the method of least squares.

The research has been carried out in the science and research work of Applied Mechanics and Environment Protection Technologies Department of the National University of Civil Defence of Ukraine "*Using of fuzzy logic and psychophysical scales in a critical assessment of the level of ecological safety"* (State Reg. № 0119U 001001, 2019 – 2021).

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Kondratenko Olexandr Mykolayovych – Cand.Sci.(Tech.), Assoc. Prof., Assoc. Prof. of Applied Mechanics and Environment Protection Technologies Dept., National University of Civil Defence of Ukraine, Kharkiv, Ukraine, e-mail: kongratenkoom2016@gmail.com, ORCID ID: 0000-0001-9687-0454, Scopus ID: 57144373800, ResearcherID: D-7346-2018, Google Scholar ID: 0IlbJMcAAAAJ.

Andronov Volodymyr Anatoliyovych – D.Sc.(Tech.), Profesor, Honored Worker of Science and Technology of Ukraine, Vice-Rector and Head of Science and Research Center, National University of Civil Defence of Ukraine, Kharkiv, Ukraine, e-mail: va_andronov@ukr.net, ORCID: 0000-0001-7486-482X, SCOPUS ID: 57192820994, Google Scholar ID: aMmzWzcAAAAJ&hl.

Koloskov Volodymyr Yuriyovych – Cand.Sc.(Tech), Assoc. Prof., Head of Applied Mechanics and Environment Protection Technologies Dept., National University of Civil Defence of Ukraine, Kharkiv, Ukraine. e-mail: koloskov_v@ukr.net, ORCID ID: 0000-0002-9844-1845; Scopus ID: 57203686820, ResearcherID: Q-9847-2018, Google Scholar ID: gP6w7a8AAAAJ.

Tkachenko Olexandra Olexandrivna – Student of Faculty of Technogenic and Ecological Safety, National University of Civil Defence of Ukraine, Kharkiv, Ukraine. e-mail: aleksandra.al@ukr.net.

Kapinos Yelyzaveta Volodymyrivna – Cadet of Faculty of Fire Ecological Safety, National University of Civil Defence of Ukraine, Kharkiv, Ukraine. e-mail: evkapinos@gmail.com.

ВИЗНАЧЕННЯ ЕТАЛОННИХ ЗНАЧЕНЬ КОМПЛЕКСНОГО ПАЛИВНО-ЕКОЛОГІЧНОГО КРИТЕРІЮ ЯК ОКРЕМОГО САМОСТІЙНОГО ЧИННИКА ЕКОЛОГІЧНОЇ БЕЗПЕКИ

Кондратенко О. М., Андронов В. А., Колосков В. Ю., Ткаченко О. О., Капінос Є. В.

У цьому дослідженні запропоновано підхід і метод на його основі для розрахункового оцінювання еталонних значень комплексного паливно-екологічного критерію проф. І.В. Парсаданова як окремого незалежного фактора екологічної безпеки та як еталонних значень психофізичної шкали часткової функції бажаності при використанні його як фактора екологічної безпеки процесу експлуатації енергоустановок з поршневими двигунами внутрішнього згоряння. Також у дослідженні надано розрахункову оцінку еталонних значень екологічних показників поршневих двигунів внутрішнього згоряння як складових комплексного паливно-екологічного критерію залежно від величин ефективної потужності та координат поля режимів роботи двигуна для різних рівнів в Україні екологічних норм – чинних та тих, що раніше діяли. Таким чином, було здійснено розрахункове оцінювання еталонних значень комплексного паливно-екологічного критерію та його компонентів і отримано розподіл таких значень по полю режимів роботи автотракторного дизеля 2Ч10,5/12, а також залежності таких еталонних величин від рівня екологічних стандартів EURO, значень ефективного коефіцієнта корисної дії двигуна та нижчої теплотворної здатності моторного палива. Отже, у дослідженні вперше запропоновано підхід до розрахункового оцінювання еталонних значень комплексного паливно-екологічного критерію проф. І.В. Парсаданова як реперних точок психофізичної шкали часткової функції бажаності Харрінгтона при використанні його у якості фактора екологічної безпеки процесу експлуатації енергоустановок з поршневим ДВЗ. Методика, побудована на запропонованому підході, для розрахункового оцінювання еталонних значень комплексного паливно-екологічного критерію проф. І.В. Парсаданова як реперних точок психофізичної шкали часткової функції бажаності придатна для отримання необхідних даних для здійснення комплексного крітеріального оцінювання рівня екологічної безпеки процесу експлуатації енергоустановок з поршневим ДВЗ з використанням узагальненої функції бажаності Харрінгтона, у структурі якої комплексний паливно-екологічний критерій виступає, як окремий фактор екологічної безпеки.

Ключові слова: технології захисту навколишнього середовища; екологічна безпека; енергоустановки; двигуни внутрішнього згоряння; еталонні значення; крітеріальне оцінювання; рівень EURO.

ОПРЕДЕЛЕНИЕ ЭТАЛОННЫХ ЗНАЧЕНИЙ КОМПЛЕКСНОГО ТОПЛИВНО-ЭКОЛОГИЧЕСКОГО КРИТЕРИЯ КАК ОТДЕЛЬНОГО САМОСТОЯТЕЛЬНОГО ФАКТОРА ЭКОЛОГИЧЕСКОЙ БЕЗОПАСНОСТИ

Кондратенко А. Н., Андронов В. А., Колосков В. Ю., Ткаченко А. А., Капинос Е. В.

В этом исследовании предложен подход и метод на его основе для расчетного оценивания эталонных значений комплексного топливно-экологического критерия проф. И.В Парсаданова как отдельного независимого фактора экологической безопасности и качестве эталонных значений психофизической шкалы частичной функции желательности при использовании его в качестве фактора экологической безопасности процесса эксплуатации энергоустановок с поршневыми двигателями внутреннего сгорания. Также в исследовании предоставлена расчетная оценка эталонных значений экологических показателей двигателей внутреннего сгорания как составляющих комплексного топливно-экологического критерия в зависимости от величин эффективной мощности и координат поля режимов работы двигателя для различных уровней экологических норм – действующих в Украине и тех, что ранее действовали. Таким образом, было осуществлено расчетное оценивание эталонных значений комплексного топливно-экологического критерия и его компонентов и получено распределение таких значений по полю режимов работы автотракторного дизеля 2Ч10,5/12, а также зависимости таких эталонных величин от уровня экологических стандартов EURO, значений эффективного коэффициента полезного действия двигателя и низшей теплотворной способности моторного топлива. Итак, в исследовании впервые предложен подход к расчетному оцениванию эталонных значений комплексного топливно-экологического критерия проф. И.В. Парсаданова как реперных точек психофизической шкалы частичной функции желательности Харрингтона при использовании его в качестве фактора экологической безопасности процесса эксплуатации энергоустановок с поршневым ДВС. Методика, построенная на предложенном подходе, для расчетного оценивания эталонных значений комплексного топливно-экологического критерия проф. И.В. Парсаданова как реперных точек психофизической шкалы частичной функции желательности пригодна для получения необходимых данных для комплексного критериального оценивания уровня экологической безопасности процесса эксплуатации энергоустановок с поршневым ДВС с использованием обобщенной функции желательности Харрингтона, в структуре которой комплексный топливно-экологический критерий выступает как отдельный фактор экологической безопасности.

Ключевые слова: технологии защиты окружающей среды; экологическая безопасность; энергоустановки; двигатели внутреннего сгорания; эталонные значения; критериальная оценка; уровень EURO.

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