UDC 504.064.4 : 621.431 : 389.14 : 528.088 **DOI: 10.20998/0419-8719.2020.2.07**

O. M. Kondratenko, V. Yu. Koloskov, Yu. F. Derkach, S. A. Kovalenko

CRITERIA-BASED ASSESSMENT OF FUEL AND ECOLOGICAL EFFICIENCY OF EXPLOITATION PROCESS OF RECIPROCATING ICE OF POWER PLANTS CONSIDERING OF EMISSION OF SULFUR OXIDES

In this study the calculation method and mathematical apparatus for assessment of the complex fuel and ecological criterion of Prof. Igor Parsadanov has been improved by considering the mass hourly emissions of sulfur oxides with the exhaust gases flow from the reciprocating ICE as a toxic pollutant. The purpose of the study is obtaining the values of complex fuel-ecological criterion that characterize the ecological safety level of diesel engine exploitation process considering the emissions of sulfur oxides as a toxic pollutant. The European Steady Cycle (according to UENCE Regulations № 49) was used as the exploitation model. A set of initial data has been obtained for the calculated criteria-based assessment of the ecological safety level of the exploitation process of power plants with a reciprocating ICE on the example of the autotractor diesel engine 2Ch10.5/12 based on the results of data processing of bench motor tests. The calculated assessment of specified criterion values considering sulfur oxides emissions was carried out. It has been detected that the value of the fuel-ecological criterion for the basic variant of considering the emissions of sulfur oxides, i.e. considering the values of sulfur content in motor fuels and oils and burning oil consumption, typical for diesel 2Ch10.5/12, differs for the variant that does not take into account this ecological safety factor, on average by 6.6 %. For the option that takes into account the modern requirements for the sulfur content in technical fluids and the technical level of modern reciprocating ICE, this difference is 0.5 %. The identified dependences are described by formulas by the method of least squares. The scientific novelty of the obtained results is that the approach of Prof. Igor Parsadanov received further development for criteria-based assessment of fuel-ecological efficiency of autotractor diesel engines exploitation process as a part of power plant considering the mass hourly emissions of fulfur oxides with RICE EG flow as the toxic pollutants and also methods for determination of such emissions and ponderability of such pollutants in direction of application of this mathematical apparatus for standardized steady testing cycles.

Key words: *environment protection technologies; ecological safety; power plants; internal combustion engines; sulfur oxides emission; criteria-based assessment, pollutants.*

Relevance of the study and problem statement

From results of analysis of scientific-technical, reference, normative and patent literature it is well known that the actual ecological status of all components of environmental – atomospheric, hydro- and lithosphere – both globally scale and on the scale of a single anthropogenically loaded and urbanized territory, causes considerable concern and has a clear tendency to deteriorate. This situation is caused by the gradual evolutionary development of civilization, which accelerated over the 20th century and was accompanied by a steady increase in the level of scientific and technological progress and the rapid development of industrial production [1 – 3].

This tendency is mainly due to the expansion of the range of countries and regions of the world, where new types of production are being developed, innovative technologies (including the so-called «nano») are being introduced, new raw material deposits are being developed, environmental standards are being developed and implemented. This naturally leads to a corresponding increase in the volume of production, and therefore the scale of environmental pollution by harmful substances and waste, as well as the progressive depletion of non-renewable natural resources. The intense component of such an impact is largely determined by the overall increase in the population living standard of the and the inextricably linked increase in the demand for industrial products, including consumer goods, food, infotainment and so on [2, 3].

For implementation of complex assessment of the values of indicators of ecological safety (ES) level of the exploitation process of power plants (PP) with reciprocating internal combustion engines (RICE), namely vehicles, which are powerful sources of negative influence on the environment [1 – 3], it is rational to use the mathematical apparatus of complex fuel-ecological criterion of Prof. Igor Parsadanov K_{fe} (NTU «KhPI») that was described in the monograph [4] and improved in the monograph [1] and developed on the basis of method [5].

Emission of legislative normalized pollutants in RICE exhaust gas (EG) flow is ES factor that must be reduced and for that special devices are used for purification of EG flow and other organizational and technical measures [6]. It is also well known that processes of thermal utilization of solid domestic wastes are also powerfull sources of emissions of pollutants into atmosphere [7, 8] as well as processes of combustion of pyrotechnics [9] and forrest fiers [10] that are detects by special measuring instruments [11, 12].

It is known that RICE operational process produces significant mass hourly emissions of sulphur dioxide SO_2 as the toxic pollutant [1, 4, 6, 13]. Taking into account that significant part of EG flow are the products of completed combustion of motor fuel, namely CO_2 and H_2O, and also that the separate RICE is not a powerful source of SO_2 emission but their role and part in world energy balance (about 70 % [4]) it is possible to conclude that considering such emissions in complex calculated assessment of values of ES level indicators of PP with RICE exploitation process is a scientific and technical problem the relevance of which has no doubt [2, 3].

It should be noted that the results obtained could be the basis for the implementation of state regulation in the field of ES ensuring, as, for example, in the field of advertising [13] and other economic aspects of complex criteria-based assessment [14].

According to the results of analysis of the mathematical apparatus of the complex fuel-ecological criterion of Prof. Igor Parsadanov K_{fe} in the monograph [1] found that its main drawback is the inability to cosider a wider range of ES factors, different in physical nature from emissions of pollutants in the gaseous state. Such studies are appropriate when assessing the ES level of PP with RICE exploitation process [1].

In the same study, the concept of improving the mathematical apparatus of the criterion K_{fe}, the original mathematical apparatus of which is described in the monograph [4], one of its main points is the partial overcoming of this drawback by introducing into the mathematical apparatus the criterion of new ES factors which are emissions of pollutants that are in the gaseous state.

Thus, in addition to the concept of an improved classification of ES factors the source of which is RICE in the PP, in addition to legislative normalized directly gaseous and aerosol pollutants in the EG flow, there are also legislative normalized indirectly, in particular sulfur oxides SO_x. As will be shown later in the paper, such ES factors can in principle be introduced into the structure of the K_{fe} criterion.

However, according to the analysis of scientific and technical literature of research on expanding the range of ES factors taken into account by the mathematical apparatus of the K_{fe} criterion, not found, and therefore the implementation of such research and analysis of its results is an urgent scientific and technical task, which has signs of scientific novelty and is of practical value.

Purpose of the study. Obtaining the values of complex fuel-ecological criterion of Prof. Igor Parsadanov that characterizes the ES level of PP with diesel engine exploitation process considering the emissions of sulphur oxides as a toxic pollutant. **Problem of the study.** Obtaining the distribution of values of complex fuel-ecological criterion for autotractor diesel engine 2Ch10.5/12 [15] on the standatdized steady testing cycle ESC (UENCE Regulations № 49 [16]) considering the emissions of sulphur oxides as a toxic pollutant. **Object of the study.** Ecological safety of diesel engine exploitation process the exploitation model of which corresponds to testing cycle ESC. **Subject of the study.** Influence of sulphur oxides emissions as a toxic pollutant on qualitative and quantitative aspects of object of the study. **Methods of the study.** Analysis of specialized scientific and technical, reference and normative literature, analysis of results of bench motor tests, basics of scientific discipline «Theory of RICE», «Theory of ESMS», «Environment protection technologies», improved mathematical apparatus of complex fuel and ecological criterion, improved mathematical apparatus of complex fuel-ecological criterion, method of least squares.

Tasks of the study

1. Analysis of features of complex fuel and ecological criterion and standatdized steady testing cycle ESC.

2. Obtaining of initial data set for the calculated assessment for standatdized steady testing cycle ESC and diesel engine 2Ch10.5/12.

3. Improvement of methods for assessing of the values of mass hourly emissions of sulphur oxides with RICE EG flow and potenderability of such ES factor as a toxic pollutant.

4. Calculated assessment of the values of complex fuel-ecological criterion for standatdized steady testing cycle ESC and analysis of its results.

Scientific novelty of the obtained results. The approach of Prof. Igor Parsadanov received further development for the criteria-based assessment of complex fuel-ecological efficiency of autotractor diesel engines exploitation process as a part of power plant considering of mass hourly emissions of sulphur oxides with RICE EG flow as a toxic pollutant and also methods for determination of such emissions and ponderability of such pollutants in direction of application of this mathematical apparatus for standardized steady testing cycles.

Practical value of the obtained results. The obtained results are suitable for providing the quailtative and quantitative assessment of ES level of different types of diesel engine exploitation process considering the emissions of sulphur oxides with RICE EG flow as the toxic pollutant.

1. Analysis of fuel-ecological criterion of Prof. Igor Parsadanov

The values of the criterion K_{fe} for *i*-th RICE steady representative operational mode with magnitude of weight factor *WF* are determined by formula (1) and its components – by formulas (2) – (5) [4, 5].

$$K_{fe} = \eta_e \cdot (1-\beta) \cdot 10^3 =$$

$$= 3600/(H_u \cdot g_e) \cdot (1 - Z_e/(Z_f + Z_e)) \cdot 10^3 \text{ ‰}; \quad (1)$$

$$Z_f = g_e \cdot P_f \text{, USD/(kW·h)}; \quad (2)$$

$$Z_e = g_e \cdot U_e = g_e \cdot \delta \cdot \sigma \cdot f \cdot g_{pr} \text{, USD/(kW·h)}; \quad (3)$$

$$g_{pr} = \sum_{k=1}^{m}\left(A_k \cdot G_k / G_{fuel}\right); \quad (4)$$

$$\sum_{m=1}^{h}\left(A_k \cdot G_k\right) = A(PM)\cdot G(PM) + A(NO_x)\cdot G(NO_x) + A(C_nH_m)\cdot G(C_nH_m) + A(CO)\cdot G(CO), \text{ kg/h}; \quad (5)$$

where the index *i* indicates the values for a separate representative mode of RICE operation or range in the its exploitation model; H_u = 42,7 MJ/kg [4] – lower fuel combustion heat; N_e – effective power, kW; G_{fuel} – hourly mass fuel consumption, kg/h; G_k – mass hourly emission of *k*-th pollutant in EG flow, kg/h; A_k – dimensionless index of relative aggressiveness of *k*-th pollutant in EG flow; *h* = 4 [4] – number of pollutants in EG flow; σ – dimensionless index of relative danger of pollution of different territories (for automotive diesel engine σ = 1,0, for tractor diesel engine 0,25 [4]); *f* – dimensionless coefficient that takes into account the character of dispersion of EG in atmosphere (for Ukraine *f* = 1,0 [4]); $\delta = P_f$ – dimension index that converts of the score assessment into monetary USD/kg; *WF* – weight factor; η_e – effective efficiency coefficient; β – coefficient of relative exploitation ecological monetary costs; Z_e and Z_f – monetary costs on compensation of ecological damage and on motor fuel, USD/(kW·h); g_e – specific effective mass hourly fuel consumption, kg/(kW··h); M_T and n_{cs} – crankshaft torque and speed, N·m and rpm; P_f = 1,36 USD/kg – price of weight unit of motor fuel (P_f = 25,0 UAH/l, excange ratio 26,0 UAH/USD, fuel density ρ_{fuel} = 0.850 kg/m^3); U_e – monetary compensation of ecological damage, USD/kg; g_{pr} – specific reduced emission of pollutants with EG flow.

The average operational value of the criterion K_{fe} describes by formula (6) as it was proposed in the study [1].

$$K_{feme} = \sqrt[7]{\sum_{i=1}^{N}\left(K_{fei}^{7} \cdot WF_i\right) / \sum_{i=1}^{N}\left(WF_i\right)} \cdot 1000, \text{ ‰}. \quad (6)$$

Method of obtaining of the values of sulfur oxides mass hourly emissions of in the criteria-based assessment

Present study is proposes the following method for such assessment that considers the toxic influence of SO_X emission on a human in accordance of which formula (5) is converted into formula (7) where value of coefficient $A(SO_X)$ is determinated by formulas (8) – (9) [5, 13].

$$\sum_{m=1}^{h}\left(A_k \cdot G_k\right) = A(PM)\cdot G(PM) + A(NO_x)\cdot G(NO_x) + A(C_nH_m)\cdot G(C_nH_m) + A(CO)\cdot G(CO) + A(SO_x)\cdot G(SO_x) \text{ kg/h}; \quad (7)$$

$$A_k = a_k \cdot \alpha_k \cdot \beta_k \cdot \delta_k, \quad (8)$$

$$a_k = \sqrt{\frac{MPC_{cd}(CO)\cdot MCP_{pz}(CO)}{MPC_{cd}(k)\cdot MPC_{pz}(k)}}, \quad (9)$$

where a_k – index of relative danger of presense of *k*-th gaseous or aerosol pollutant in atmospheric air that a human breathes; α_k – correction that takes into account the probability of accumulation of *k*-th gaseous or aerosol pollutant in environment components, trophic chaines and admission to the human body by non-inhalation way; β_k – correction that takes into account the probability of formation of other (secondary) pollutants, more harmful than the original, by the source of the *k*-th gaseous or aerosol pollutant emitted into the atmosphere; δ_k – correction that takes into account the impact of *k*-th gaseous or aerosol pollutant on other recipients except a human; $MPC_{ad}(CO)$ and $MPC_{ot}(CO)$, $MPC_{ad}(k)$ and $MPC_{ot}(k)$ – maximum permissible concentration of reference (A_{CO} = 1.0, $MPC_{ad}(CO)$ = 3.0 mg/m^3, $MPC_{ot}(CO)$ = 20.0 mg/m^3 [5, 24]) and *k*-th pollutant in air average day-and-night and maximal one-time, mg/m^3.

The source [13] contains information on the components of formulas (8) and (9), obtained from the analysis of the content of the source [4], and summarized in Table. 1 and illustrated in Fig. 1. Thus, the value of $A(SO_x)$ is 22, which is 9 times less than the value of *A*(PM), twice less than the value of $A(NO_x)$ and 7 times higher than the value of $A(C_nH_m)$.

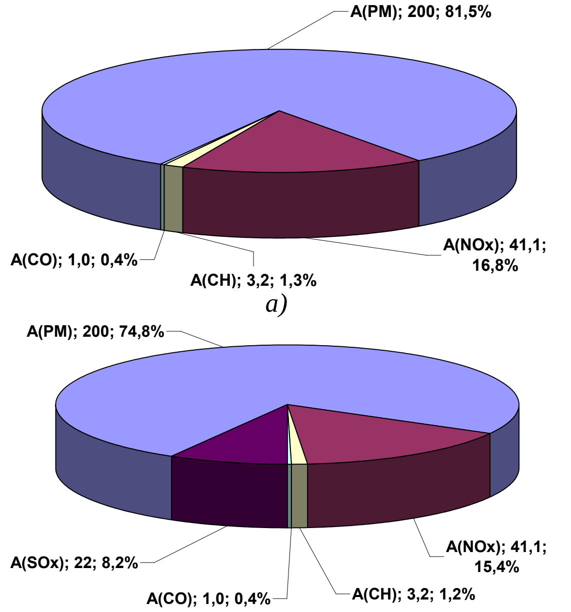
Table 1. Parameters of legislative normalized pollutants as a part of EG of diesel RICE [4]

Pollutant	Indicator				
	a_k	α_k	β_k	δ_k	A_k
CO	1.0	1.0	1.0	1.0	1.0
C_nH_m	0.63	1.0	5.0	1.0	3.16
NO_2	27.4	1.0	1.0	1.5	41.1
SO_2	11.0	1.0	1.0	2.0	22.0
C	17.5	2.0	1.0	1.2	41.5
PM	–	–	–	–	200

The structure of the mass hourly emissions of pollutants in the composition of EG of RICE, taken into account in the criterion assessment by the criterion K_{fe} for special operating modes of the diesel engine D21A1 (2Ch10.5/12 in accordance with ISO 3046-1:2002) is shown in Fig. 2.

To determine the value of $G(SO_x)$, which is a necessary condition for the application of formula (7) and formula (1), this study used an approach based on the following assumptions.

1) The source of SO_x oxides in the EG aerosol is redox reactions in the combustion chamber of RICE between sulfur (free or chemically bound) contained in motor fuel and motor oil, with freshly charged air oxygen O_2.



b)

Fig. 1 – Structure of weights of factors of ecological component of criterion K_{fe} with considering SO_x emission (b) and without such considering (a)

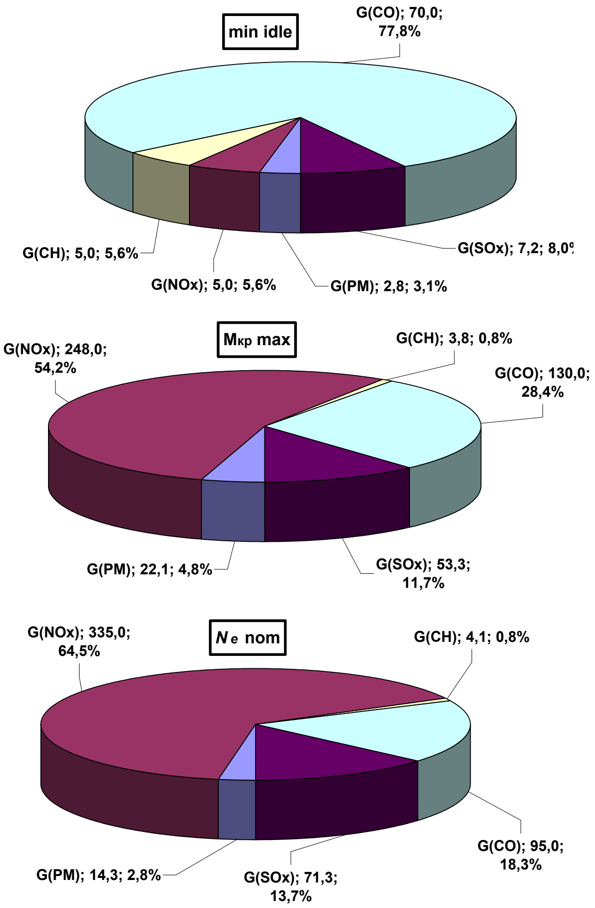


Fig. 2. Structure of the mass hourly emissions of pollutants in the RICE EG flow with considering in the criteria-based assessment by the criterion K_{fe} for special operation modes of the diesel engine 2Ch10.5/12

That is, their hourly mass emission $G(SO_x)$ is determined by the hourly mass consumption of G_{fuel} fuel and the consumption of engine oil G_{oil}, which are related to each other for a certain technical state of RICE by the value of relative oil consumption C_{of}.

2) All sulfur from motor fuel and motor oil is completely oxidized during combustion in the combustion chamber, i.e. all sulfur oxides SO_x in the aerosol EG are SO_2 dioxide. In fact, SO_2 accounts for about 94 % by weight, and the rest is converted into sulfur trioxide SO_3 (up to 2 % wt.), sulfates (up to 2 % wt., are part of PM), sulfuric acid H_2SO_4 (up to 2 % wt.), hydrogen sulfide H_2S (less than 1.0 % wt.) [17, 18].

That is, the value of $G(SO_x)$ is determined by the relative sulfur content in motor fuel C_{Sf} and in motor oil C_{So} (in % wt.) Taking into account the mass of oxygen in SO_2 according to stoichiometric ratios in the equation of the corresponding chemical reaction (10).

$$S + O_2 \rightarrow SO_2 \qquad (10)$$

The molar mass of reagents and reaction products is: sulfur μ(S) = 32 g/mol, oxygen μ(O) = 16 g/mol, then the molar mass of sulfur dioxide is:

$\mu(SO_x) = \mu(S) + 2 \cdot \mu(O) = 32 + 2 \cdot 16 = 64$ g/mol.

Then the mass hourly emission of sulfur dioxide G_{SO2} is twice the mass hourly consumption of sulfur by the G_S engine – see formula (11).

$$G_{SO2} = \mu(SO_x) / \mu(S) \cdot G_S = 2 \cdot G_S, \text{ kg/h}. \qquad (11)$$

The mass hourly consumption of sulfur by the engine G_S is proposed to be determined by formula (12).

$$G_S = G_{Sf} + G_{So}, \text{ kg/h}. \qquad (12)$$

where G_{Sf} and G_{So} – mass hourly consumption of sulfur by the engine, due to the consumption of motor fuel and burning motor oil consumption, respectively, kg/h.

The mass hourly consumption of sulfur by the engine caused by the consumption of motor fuel G_{Sf} is proposed to determine by formula (13), and caused by the burning motor oil consumption G_{So} – by formula (14).

$$G_{Sf} = G_{fuel} \cdot C_{Sf} / 100, \text{ kg/h}; \qquad (13)$$

$$G_{So} = G_{oil} \cdot C_{So} / 100 = G_{fuel} \cdot C_{of} \cdot C_{So} / 100, \text{ kg/h}, \qquad (14)$$

where G_{fuel} – mass hourly consumption of motor fuel, kg/h; C_{Sf} – relative sulfur content in motor fuel, % wt.; C_{So} – relative sulfur content in engine oil, % wt.; C_{of} – relative burning motor oil consumption, % wt.

Then formula (11) takes the form of formula (15).

$$G_{SO2} = 2 \cdot G_{fuel} \cdot (C_{Sf} + C_{of} \cdot C_{So}) / 100 = G_{fuel} \cdot k_{SO2}, \text{ kg/h}. \qquad (15)$$

where k_{SO2} – coefficient that converts the value of fuel consumption into the value of SO_2 emissions, determined by the formula (16).

$$k_{SO2} = 2 \cdot (C_{Sf} + C_{of} \cdot C_{So}) / 100. \qquad (16)$$

Thus, the value of the mass hourly emission of sulfur oxides $G(SO_2)$ subject to the proposed assumeptions is completely determined by the values G_{fuel}, C_{Sf},

C_{So} and C_{of}.

The value of G_{fuel} is completely determined by the level of perfection of the RICE working process and design, its current technical condition and model of its exploitation and is not legislly normalized.

The value of C_{Sf}, normalized by the relevant standards and ranges from 0.001 % wt. according to the standard EURO V [19] up to 4.5 % wt. for heavy motor fuels according to the standard [20], and for diesel fuel, for the consumption of which the autotractor diesel engine 2Ch10.5/12 was designed, according to the standard [21] this value is 0.2 – 0.5 % wt.

The amount of sulfur in gasoline ranges from 0.1 % wt. according to the standard [22] and up to 10 ppm (i.e. 0.0001 % wt.) for the level of EURO V according to the standard [23].

The value of C_{So} is determined by the nomenclature and number of additives to the oil that meet its purpose, according to standards [24, 25], the requirements of API, ASTM, ILSAC, JASO, ACEA, SAE and according to the reference literature [26] and ranges from 0.1 % wt. up to 1.0 % wt. For 2Ch10.5/12 diesel engine according to its technical documentation motor oil M10G2 (in the summer) and M8G2 (in the winter) for which this value makes 0,5 % wt. should be applied.

The value of C_{of} is determined by the type of RICE, its technical level, current technical condition, mode of operation. In particular, for technically sound: gasoline RICE it is 0.1… 0.25 % wt., diesels – 0.3 … 0.5 % wt., supercharged RICE – 0.8… 1.0 % wt. [27, 28].

In addition, it is known that for some types of RICE motor oil enters the combustion chamber not through the gap between the piston and the cylinder liner, but together with the motor fuel, because it is added there according to technical requirements – these are gasoline two-stroke engines with crank chamber purge for motorcycles and motorized equipment. In this case, the oil content in the fuel reaches 5.0 % wt. [29].

Thus, the above influencing factors will vary in the calculation study according to Table 2. The basic values that determine the mass emission of SO_2 at a certain constant magnitude of fuel consumption G_{fuel} are as follows: C_{Sfb} = 0.5 %, C_{Sob} = 0.5 %, C_{fob} = 0.5 %.

Table 2. Parameters of influencing factors

Value	**Measur. units**	**Magnitude**		
G_{fuel}	**kg/h**	0.5	distribution on the field of operating modes	4.5
C_{Sf}	**%**	0.05	0.5	5.0
C_{So}	**%**	0.1	0.5	1.0
C_{of}	**%**	0.0	0.5	5.0

The calculated study of the influence of values of C_{Sf}, C_{So} and C_{fo} on the value of the coefficient k_{SO2}, was carried out, the results of which are illustrated in Fig. 3 – 5.

Fig. 3 contains graphs of the dependences of values of the coefficient k_{SO2} on magnitudes of values C_{Sf} and C_{Co} for different constant magnitudes of the value C_{of}. It shows that they are all linear, have one angle of inclination to the abscissa axis, and the distance between them depends on the magnitude of the value of S_{of}, when Sof = 0 % coincide.

Fig. 4 shows graphs of dependences of the values of the coefficient k_{SO2} on the magnitudes of the value of S_{of} at the basic magnitudes of the value of C_{So} and different constant magnitudes of the value of C_{Cf}, and in Fig. 5 – graphs of the magnitudes of the value of S_{of} at the basic magnitudes of the value of C_{Sf} and different constant magnitudes of the value of C_{So}. Fig. 4 shows that such dependences are linear, have one angle of inclination to the abscissa, in contrast to the graphs in Fig. 5 coming from a single point that is not the origin.

In general, within the limits specified in Table 2 ranges of change of the values included in the formula (15), the value of the coefficient k_{SO2} varies from 0.001 (C_{Sf} = 0.05 %, C_{So} = 0.1 %, C_{fob} = 0.0 %) to 0.200 (C_{Sf} = 5.0 %, C_{So} = 1.0 %, C_{fob} = 5.0 %). Therefore, for the basic calculation option, the value of G_{SO2} is 1.5 % of the value of G_{fuel} for any steady regime of operation of the RICE, i.e. k_{SO2b} = 0.015 (C_{Sf} = 0.5 %, C_{So} = 0.5 %, C_{fob} = 0.5 %) (see formulas (15) and (16)).

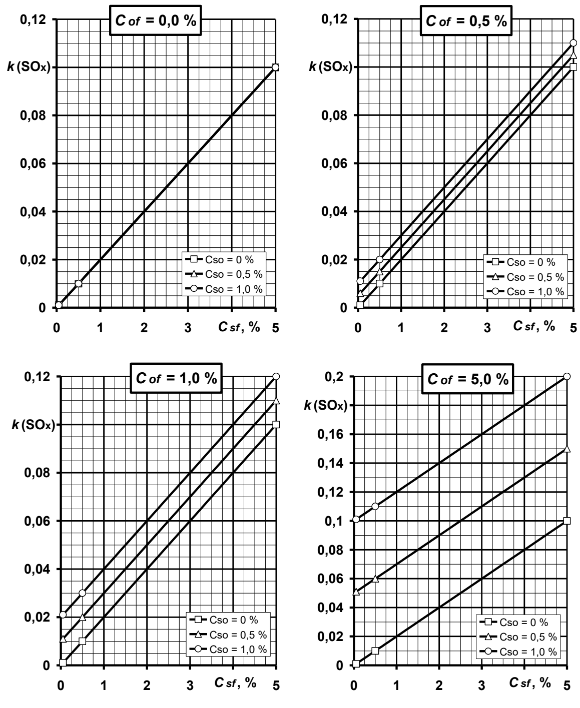


Fig. 3 – Graphs of dependences of k_{SO2} coefficient values on values of C_{Sf} and C_{So} values for different constant values of C_{of} value

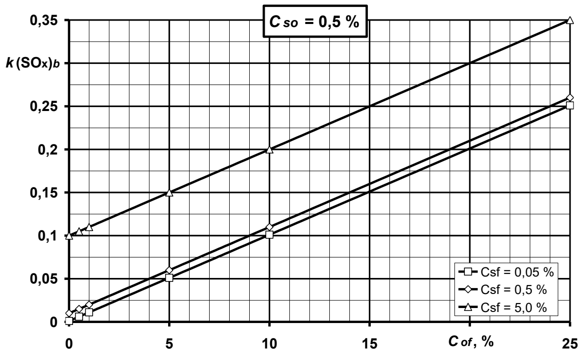


Fig. 4. Graphs of dependences of values of the coefficient k_{SO2} on magnitudes of the value of S_{of} at the basic magnitudes of the value of C_{So} and different constant magnitudes of the value of C_{Sf}

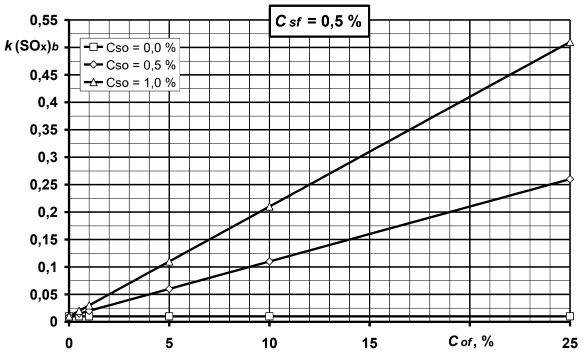


Fig. 5. Graphs of dependences of values of the coefficient k_{SO2} on the magnitudes of the value of S_{of} at the basic magnitudes of the value of C_{Sf} and different constant magnitudes of the value of C_{So}

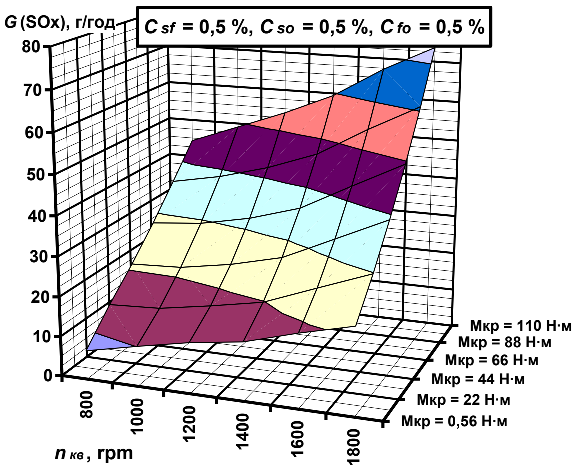


Fig. 6. Distribution of magnitudes of value of G_{SO2} on the field of operating modes of the 2Ch10.5/12 diesel engine at base value of coefficient k_{SO2} = 0.015

The calculated evaluation of values according to the proposed method of SO_x emission for the whole field of operating modes of the 2Ch10.5/12 diesel engine for the following characteristic values of the coefficient k_{SO2} was carried out:

– basic value of k_{SO2} = 0.015 at C_{Sf} = 0.5 %, C_{So} = = 0.5 %, C_{fob} = 0.5 %), presented on Fig. 6;

– maximum value of k_{SO2} = 0.200 at C_{Sf} = 5.0 %, C_{So} = 1.0 %, C_{fob} = 5.0 %), presented on Fig. 7;

– minimum value of k_{SO2} = 0.001 at C_{Sf} = 0.05 %, C_{So} = 0.1 %, C_{fob} = 5.0 %), presented on Fig. 8.

Fig. 6 – 8 shows that the smallest values of $G(SO_x)$ reaches the minimum idle mode, and the largest – at nominal power mode. For the basic variant, the value of $G(SO_x)$ varies in the range from 7.3 to 73.6 g/h, i.e. changes in 10 times according to the over the field of RICE operating modes.

Averaged over the entire field of RICE operating modes for diesel engine 2Ch10.5/12 magnitudes of the value of $G(SO_x)$ depending on the value of the coefficient k_{SO2} are illustrated in Fig. 9 and described by formula (17).

$$G_{SO2me} = 2250 \cdot k_{SO2}, \text{ g/h.} \qquad (17)$$

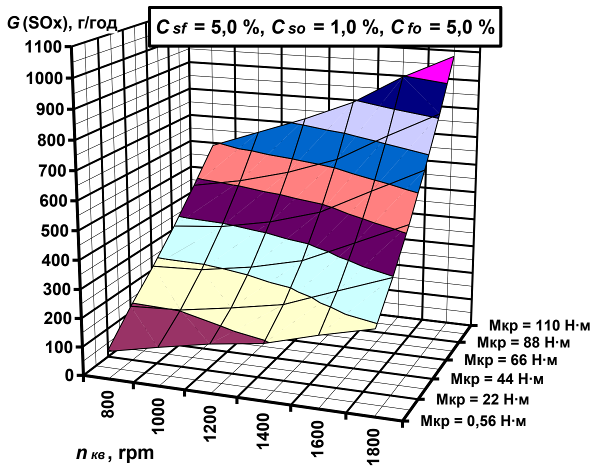


Fig. 7. Distribution of magnitudes of value of G_{SO2} on the field of operating modes of the 2Ch10.5/12 diesel engine at base value of coefficient k_{SO2} = 0.200

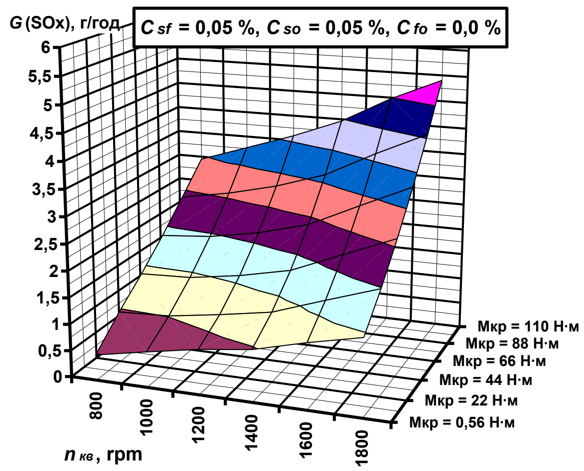


Fig. 8. Distribution of magnitudes of value of G_{SO2} on the field of operating modes of the 2Ch10.5/12 diesel engine at base value of coefficient k_{SO2} = 0.001

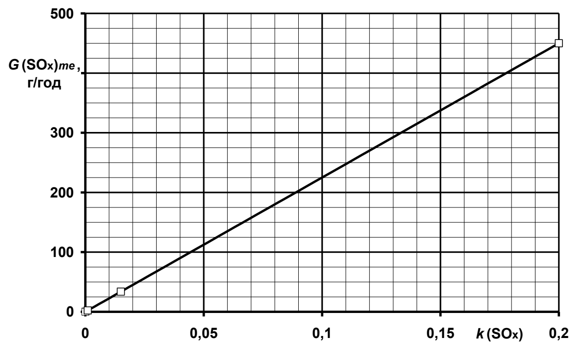


Fig. 9. Graph of the dependence of the magnitudes of the value of G_{SO2}, averaged over the entire field of operation modes of the 2Ch10.5/12 diesel engine, from the value of the coefficient k_{SO2}

On Fig. 9 shows that this dependence is linear, and its graph is based on the origin. Such average values of $G(SO_x)$ emissions in the studied range of changes in the values of the coefficient k_{SO2} = 0.0 – 0.200 vary from 0 to 450 g/h.

Thus, in this part of the article the method of obtaining the values of the mass hourly emission of sulfur oxides in the EG flow of diesel RICE is presented and it is applied to the case of diesel engine 2Ch10.5/12.

3. Obtaining an initial data set for a standardized steady testing cycle ESC

The standardized steady testing cycle ESC (European Steady Cycle) described in standard [16] is used to build a test program for passenger vehicles and contains 13 steady modes of RICE operation. Technical and economical, as well as ecological indicators of 2Ch10.5/12 diesel engine, the exploitation model of which is ESC testing cycle was obtained and showed in monograph [1] and studies [2, 3, 30–34]. Technical characteristic of 2Ch10.5/12 diesel engine is contained in source [15].

4. Results of calculated study and their analysis

The results of the calculated study of $G(SO_x)$ emission values and the complex fuel-ecological criterion K_{fe} for the reference and baseic variants and the ESC test cycle are illustrated on Fig. 10 – 14.

Distribution of the values of the mass hourly emission of sulfur oxides $G(SO_x)$ and the value of $\delta\Sigma(A_k{\cdot}G_k)$ by the modes of the ESC cycle is illustrated on Fig. 10, and the values of the coefficient K_{fe} and the value of obtained effect δK_{fe} – on Fig. 11.

Fig. 10 shows that the value of $G(SO_x)$ in the modes of the cycle ESC varies from 7.2 g/h (mode № 1) to 71.3 g/h (mode № 10), and the value of $\delta\Sigma(A_k \cdot G_k)$ – from 7.5% (mode № 6) to 18.9 (mode № 1).

Fig. 11 shows that the values of K_{fe} for the reference variant (excluding the value of $G(SO_x)$) for the modes of the ESC cycle varies from 2.7 ‰ (mode № 1) to 64.4 ‰ (mode № 4), and taking into account the emission of sulfur oxides SO_2 according to the basic variant (CS_f = 0.5 %, C_{So} = 0.5 %, C_{fob} = 0.5 %) these values change by the value of δK_{fe} in the range from –5.8 % (mode № 6) to –10.7 % (mode № 1).

In the second stage of the calculation study, the evaluation results for the following options were obtained (see Table 3).

Variant A «Reference», without taking into account the value of $G(SO_x)$, i.e. for which C_{Sf} = 0 %, C_{So} = = 0 %, C_{fob} = 0 %, k_{SOx} = 0.

Variant B «Basic», the value of $G(SO_x)$ is taken into account for the typical case for diesel engine 2Ch10.5/12, i.e C_{Sf} = 0.5 %, C_{So} = 0.5 %, C_{fob} = 0.5 %, k_{SOx} = 0.015.

Variant C «Optimistic», the value of $G(SO_x)$ is taken into account for the most environmentally advantageous case, i.e. C_{Sf} = 0.0 5%, C_{So} = 0.1 %, C_{fob} = 0 %, k_{SOx} = 0.001.

Variant D «Pessimistic», the value of $G(SO_x)$ is taken into account for the least environmentally favourable case, i.e. C_{Sf} = 5.0 %, C_{So} = 1.0 %, C_{fob} = 5.0 %, k_{SOx} = 0.200.

Results of the comparative calculation study for variants A, B, C, D and the ESC cycle are summarized on Fig. 12 and 13.

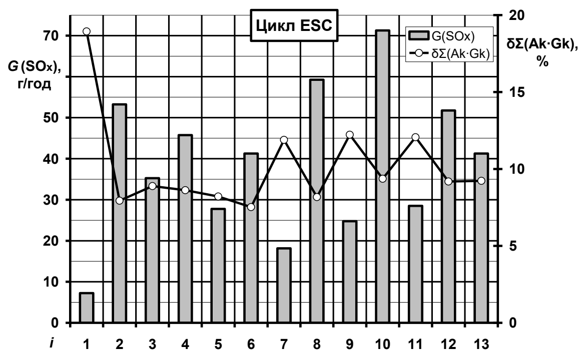


Fig. 10. Distribution of values of $G(SO_x)$ and $\delta\Sigma(A_k{\cdot}G_k)$ by ESC cycle modes for the basic study variant

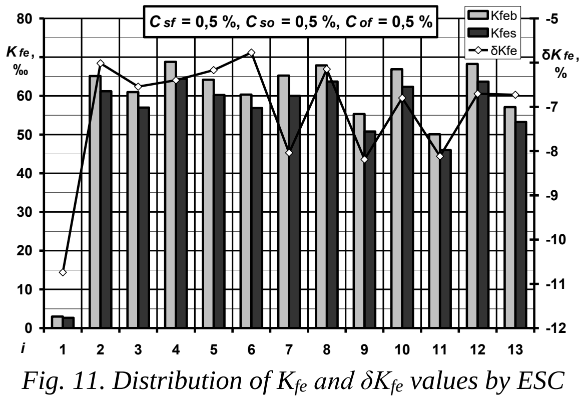


Fig. 11. Distribution of K_{fe} and δK_{fe} values by ESC cycle modes for Reference and Basic study variants

Table 3. Variants of calculated study

Variant		Parameter			
Sign.	**Title**	C_{sf}, %	C_{so}, %	C_{fo}, %	k_{SOx}, –
A	**Reference**	0.0	0.0	0.0	0.0
B	**Basic**	0.5	0.5	0.5	0.015
C	**Optimistic**	0.05	0.1	0.0	0.001
D	**Pessimistic**	5.0	1.0	5.0	0.200

Fig. 12 and 13 show distribution of values of K_{fe} and δK_{fe} by modes of the ESC cycle for all study variants. They show that the value of fuel and ecological efficiency of the 2Ch10.5/12 diesel engine exploitation process all options, considering the emission of sulfur oxides are inferior to the reference variant A; variant C is almost no different from variant A (within 0.4… 0.8 %), the difference between variant B and variant A is more expressed (about 5.8…10.7 %), and variant D is significantly inferior to variant A. approximately 45… 62 %).

The results of estimating the average operational values of K_{fe} and δK_{fe} for all variants of the calculation study and depending on the value of the coefficient k_{SOx} are illustrated on Fig. 14 and 15 and is described by the method of least squares by polynomials of the 2nd degree – see formulas (18) and (19).

$$K_{feme} = 4{,}848 \cdot 10^2 \cdot k^2_{SO2} - 2{,}464 \cdot 10^2 \cdot k_{SO2} + 6{,}245 \cdot 10^1;\ R^2 = 0{,}999; \quad (18)$$

$$\delta K_{feme} = 7{,}741 \cdot 10^2 \cdot k^2_{SO2} - 3{,}953 \cdot 10^2 \cdot k_{SO2} - 2{,}652 \cdot 10^{-1};\ R^2 = 0{,}999. \quad (19)$$

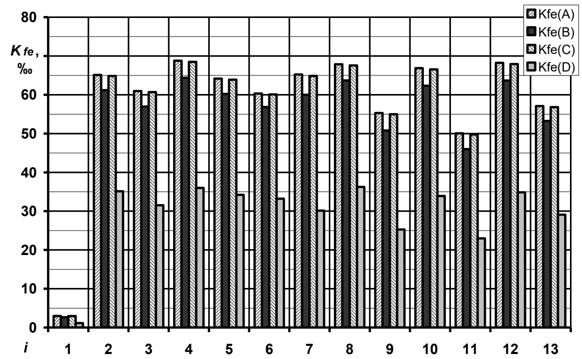


Fig. 12. Distribution of K_{fe} values by ESC cycle modes for all study variants

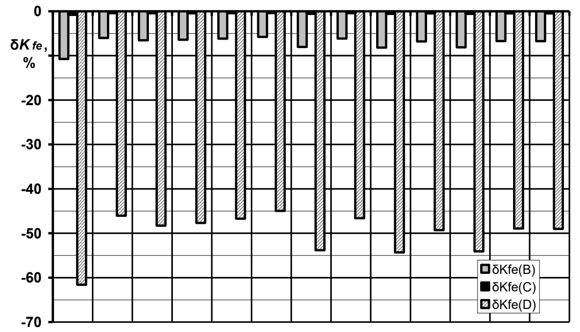


Fig. 13. Distribution of δK_{fe} values by ESC cycle modes for all study variants

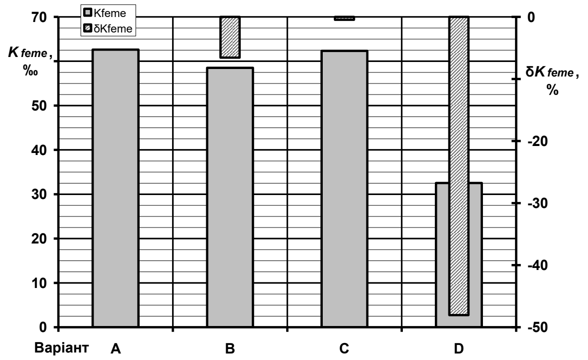


Fig. 14. Average operational values of K_{fe} and δK_{fe} for all study variants

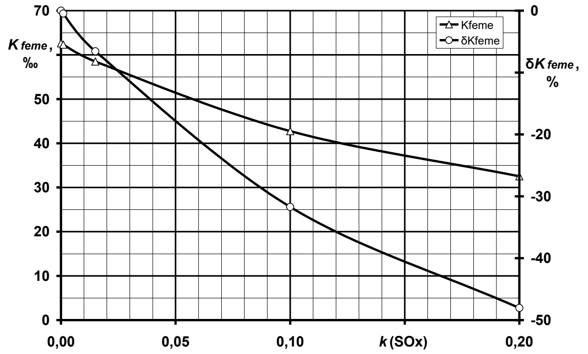


Fig. 15. Graphs of dependence of average operational values of K_{fe} and δK_{fe} on the value of coefficient k_{SOx}

Therefore, in this part of the work the criteria-based assessment of the ES level of the RICE exploitation process on the example of the autotractor diesel engine 2Ch10.5/12 is carried out considering the emissions of sulfur oxides with the flow of EG and its results are analyzed.

Conclusions

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

1. The method of calculated assessment of values of complex fuel-ecological criterion of Prof. Igor Parsadanov considering the mass hourly emissions of sulfur oxides with the flow of EG of RICE and the burning engine oil consumption. The essence of the proposed approach is to obtain the values of the mass hourly emission of sulfur oxides as the product of the value of the mass hourly consumption of motor fuel and the coefficient that takes into account the sulfur content of motor fuels and oils and burning oil consumption.

2. A set of initial data for the calculation study for the steady test cycle ESC was obtained.

3. The calculated assessment of values of the complex fuel-ecological criterion considering the emissions of sulfur oxides with the flow of EG of RICE for the use of motor fuels and oils with different sulfur

content and different values of burning engine oil consumption.

It was found that the value of the fuel-ecological criterion for the basic variant of taking into account emissions of sulfur oxides, i.e. with the values of sulfur content in motor fuels and oils and burning oil consumption, typical for 2Ch10.5/12 diesel engine, differs for the variant that does not take into account this ES factor, on average by 6.6 %.

For the variant that takes into account the current requirements for sulfur content in technical fluids and the technical level of modern RICE, this difference is 0.5 %.

The 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).

References:

1. Kondratenko O.M. Metrological aspects of complex criteria-based assessment of ecological safety level of exploitation of reciprocating engines of power plants: Monograph / O.M. Kondratenko. – Х.: Стиль-Издат (ФОП Бровін О.В.), 2019. – 532 с. 2. Kondratenko O.M. Taking into account the emissions of CO_2 as a toxic pollutant and as a greenhouse gas in fuel and ecological complex criteria-based assessment of diesel-generator operation process / O.M. Kondratenko // Technogenic and Ecological Safety. – Х.: НУЦЗУ, 2019. – № 6(2/2019). – С. 12 – 23. – DOI: 10.5281/zenodo.3558960. 3. Kondratenko O.M. Assessment of ecological and chemical efficiency of exploitation process of reciprocating ICE of vehicle with concideration of emission of sulphur oxides, benzo (a)pyrene and polycyclic aromatic hydrocarbones / O.M. Kondratenko // Technogenic and Ecological Safety. – Х.: НУЦЗУ, 2020. – № 7(1/2020). – С. 38 – 50. – DOI: 10.5281 /zenodo.3780076. 4. Парсаданов І.В. Підвищення якості і конкурентоспроможності дизелів на основі комплексного паливно-екологічного критерію: монографія / І.В. Парсаданов. – Х.: Центр НТУ «ХПІ», 2003. – 244 с. 5. Временная типовая методика определения экономической эффективности осуществления природоохранных мероприятий и оценки экономического ущерба, причиняемого народному хозяйству загрязнением окружающей среды / А.С. Быстров, В.В. Варанкин, М.А. Виленский и др. – М.: Экономика, 1986. – 96 с. 6. Сучасні способи підвищення екологічної безпеки експлуатації енергетичних установок: монографія / С.О. Вамболь, О.П. Строков, В.В. Вамболь, О.М. Кондратенко. – Х.: Стиль-Издат (ФОП Бровін О.В.), 2015. – 212 с. 7. Substantiation of expedience of application of high-temperature utilization of used tires for liquefied methane production / S. Vambol, V. Vambol, O. Kondratenko, V. Koloskov, Y. Suchikova // Journal of Achievements in Materials and Manufacturing Engineering. – 2018. – Vol. 87. Issue 2. – P. 77–84. – DOI: 10.5604/01.3001.0012. 2830. 8. Investigation of the energy efficiency of waste utilization technology, with considering the use of low-temperature separation of the resulting gas mixtures / S. Vambol, V. Vambol V. Sobyna, V. Koloskov, L. Poberezhna // Energetika. – 2018. – Vol 64, No 4 (2018). – P. 186–195. – DOI: 10.6001/energetika.v64i4.3893. 9. Physicochemical principles of the technology of modified pyrotechnic compositions to reduce the chemical pollution of the atmosphere / M.V. Kustov, V.D. Kalugin, V.V. Tutunik, O.V. Tarakhno // Voprosy Khimii i Khimicheskoi Tekhnologii. – 2019. – No. 1 (2019). – P. 92–99. – DOI: 10.32434/0321-4095-2019-122-1-92-99. 10. Results of experimental research into correlations between hazardous factors of ignition of materials in premises / B. Pospelov, E. Rybka, R. Meleshchenko, S. Gornostal, S. Shcherbak // EasternEuropean Journal of Enterprise Technologies. – 2017. – # 6 (10-90). –P. 50–56. – DOI: 10.15587/ 1729-4061.2017.117789. 11. Development of the method for rapid detection of hazardous atmospheric pollution of cities with the help of recurrence measures / B. Pospelov, E. Rybka, R. Meleshchenko, P. Borodych, S. Gornostal // Eastern-European Journal of Enterprise Technologies. – 2019. – Vol. 1, No 10 (97). – P. 29–35. – DOI: doi.org/10.15587/1729-4061.2019.155027. 12. Research into dynamics of setting the threshold and a probability of ignition detection by selfadjusting fire detectors / B. Pospelov, V. Andronov, E. Rybka, S. Skliarov // EasternEuropean Journal of Enterprise Technologies. – 2017. – # 5 (9-89). – P. 43–48. – DOI: 10.15587/ 1729-4061. 2017.110092. 13. Каніло П.М. Автомобіль та навколишнє середовище / П.М. Каніло, І.С. Бей, О.І. Ровенський. – Х.: Прапор, 2000. – 304 с. 14. Shvedun V.O. Experience of EU countries in ensuring public administration of advertising activity / V.O. Shvedun // Actual Problems of Economics. – 2015. – № 168 (6). – art. no. A084. – P. 84–90. 15. Дизели с воздушным охлаждением Владимирского тракторного завода / В.В. Эфрос [и др.]. – М.: Машиностроение, 1976. – 277 с. 16. Uniform provision concerning the approval of compression ignition (C.I.) and natural gas (NG) engines as well as positive-ignition (P.I.) engines fuelled with liquefied petroleum gas (LPG) and vehicles equipped with C.I. and NG engines and P.I. engines fuelled with LPG, with regard to the emissions of pollutants by the engine: regulation United Nations Economic and Social Council Economics Commission for Europe Inland Transport Committee Working Party on the Construction of Vehicles of 26 January 2013 year Regulation No. 49, Revision 6 [Electronic recourse]. – Geneva: UNECE, 2013. – 434 p. – URL: https:// www.unece.org/fileadmin/DAM/trans/main/wp29/wp29regs/2013/R049r6e.pdf. 17. Сигал И.Я. Очистка промышленных выбросов от оксидов серы и азота / И.Я. Сигал, В.И. Славин, В.В. Шило. –Х.: Оригинал,1999. –142 с. 18. Руководящие указания по переводу котлоагрегатов, работающих на сернистых жидких топливах в режиме сжигания с предельно малыми избытками воздуха. – М.: Союзтехэнерго, 1980. – 34 с. 19. ГОСТ 32511-2013. Топливо дизельное ЕВРО. Технические условия. – М.: Стандартинфом, 2014. – 19 с. 20. ГОСТ Р 54299-2010. Топлива судовые. Технические условия. – М.: Стандартинфом, 2012 – 36 с. 21. ГОСТ 305-82. Топливо дизельное. Технические условия. – М.: Стандартинфом, 2009. – 22 с. 22. ГО СТ 2084-77. Бензины автомобильные. Технические условия. – М.: МПК Изд-во стандартов, 2006. – 9 с. 23. ГОСТ Р 51866-2002. Топлива моторные. Бензин неэтилированный. Технические условия. – М.: Стандартинфом, 2009. – 43 с. 24. ГОСТ 12337-84. Масла моторные для дизельных двигателей. Технические условия.

– М.: МПК Изд-во стандартов, 2002. – 12 с. 25. ГОСТ 33305-2015. Масла смазочные. Метод определения фосфора, серы, кальция и цинка энергодисперсионной рентгенофлуоресцентной спектроскопией. – М.: Стандартинфом, 2016. – 11 с. 26. Топлива, смазочные материаллы, технические жидкости. Ассортимент и применение: Справочник / И.Г. Анисимов, К.М. Бадыштова, С.А. Бнатов и др.; под ред. В.М. Школьникова. Изд. 2-е перераб. и доп. - М.: Издательский центр "Техинформ", 1999. – 596 с. 27. Нормы расхода моторних масел на эксплуатационные нужды стационарных дизельних электростанций РД 34.10.563-94. – М.: ОРГРЕС, 1997. – 7 с. 28. Р 3112194-0366-03. Новые нормы рас хода топлив и смазочных материалов на автомобильном транспорте. – М.: ИНФРА-М, 2003. – 50 с. 29. Мотоциклы ИЖ Планета и ИЖ Юпитер 4-го и 5-го поколений. Руководство по ремонту и техническому обслуживанию / под ред. А.М. Перевозчикова. – М.: АТ-ЛАС-ПРЕСС, 2006. – 256 с. 30. Mathematical model of efficiency of diesel particulate matter filter / O.M. Kondratenko, O.P. Strokov, S.O. Vambol, A.M. Avramenko // Scientific Bulletin of National Mining University. – 2015. – Issue 6 (150). – С. 55–61. 31. Assessment of improvement of ecological safety of power plants by arrangement of pollutants neutralization system / S. Vambol, V. Vambol, O. Kondratenko, Y. Suchikova, O. Hurenko // Eastern-European Journal of Enterprise Technologies. – 2017. – № 3/10 (87). – С. 63–73. 32. Criteria based assessment of the level of ecological safety of exploitation of electric generating power plant that consumes biofuels / O. Kondratenko, I. Mishchenko, G. Chernobay, Yu. Derkach, Ya. Suchikova // Book of Papers of 2018 IEEE 3rd International International Conference on Intelligent Energy and Power Systems (IEPS–2018), 10–14 September 2018. – Kharkiv, NTU «KhPI». – С. 185–189, DOI: 10.1109/IEPS.2018.8559570. 33. Description of mass hourly emissions of particulate matter of diesel engine by beta-distribution with taking into account the passport accuracy of gas analyzer / O.P. Strokov, O.M. Kondratenko, V.Yu. Koloskov, I.V. Mishchenko // Двигуни внутрішнього згоряння. – Х: НТУ «ХПІ», 2019. – № 1. – pp. 49 – 62. – DOI: 10.20998/0419-8719.2019.1.09. 34. Features of determination of the efficiency of devices for improvement of ecological safety level of vehicles with reciprocating ICE exploitation / O.M. Kondratenko, G.O. Chernobay, Ju.F. Derkach. S.A. Kovalenko // Двигуни внутрішнього згоряння. – Х: НТУ «ХПІ», 2019. – № 2. – pp. 36 – 44. – DOI: 10.20998/0419-8719.2019.2.07.

Bibliography (transliterated):

1. Kondratenko O.M. (2019), Metrological aspects of complex criteria-based assessment of ecological safety level of exploitation of reciprocating engines of power plants : Monograph, Publ. Style-Izdat (FOP Brovin O.V.), NUCPU, Kharkiv, Ukraine, 532 p. 2. Kondratenko O.M. (2019), "Taking into account the emissions of CO_2 as a toxic pollutant and as a greenhouse gas in fuel and ecological complex criteria-based assessment of diesel-generator operation process", Technogenic and Ecological Safety, № 6(2/2019), pp. 12–23, DOI: 10.5281/zenodo.3558960. 3. Kondratenko O.M. (2020), "Assessment of ecological and chemical efficiency of exploitation process of reciprocating ICE of vehicle with concideration of emission of sulphur oxides, benzo(a)pyrene and polycyclic aromatic hydrocarbones", Technogenic and Ecological Safety, № 7(1/2020), pp. 38–50, DOI: 10.5281/zenodo.3780076. 4. Parsadanov, I.V. (2003), "Improving the quality and competitiveness of diesel engines based on complex fuel and ecological criteria: monograph" [Pidvychshennya yakosti ta konkurentospromozhnosti dyzeliv na osnovi kompleksnogo palyvno-ekologichnogo kryteriyu: monografiya], Kharkiv, Publ. NTU "KhPI", 244 p. 5. Bystrov A.S., Varankiv V.V., Vilensky M.A. at al. (1986). "Temporary standard methodology for determining the economic efficiency of environmental protection measures and assessing the economic damage caused to the national economy by environmental pollution", Moscow, Publ. Ekonomika, 96 p. 6. Vambol S.O., Strokov, O.P., Vambol,V.V., Kondratenko, O.M. (2015), "Modern methods for improving the ecological safety of power plants exploitation: monograph" [Suchasni sposoby pidvyshchennya ekologichniyi bezpeky ekspluataciyi energetychnyh ustanovok: monografiya], Kharkiv, Publ. Styl-Izdat, 212 p., URL: http://repositsc.nuczu.edu.ua/handle/ 123456789/3529. 7. Vambol S., Vambol V., Kondratenko O., Koloskov V., Suchikova Y. (2018), "Substantiation of expedience of application of high-temperature utilization of used tires for liquefied methane production", Journal of Achievements in Materials and Manufacturing Engineering, Vol. 87, Issue 2, pp. 77–84, DOI: 10. 5604/01.3001.0012.2830. 8. Vambol S., Vambol V. Sobyna V., Koloskov V., Poberezhna L. (2018), "Investigation of the energy efficiency of waste utilization technology, with considering the use of low-temperature separation of the resulting gas mixtures", Energetika, Vol 64, No 4 (2018), pp. 186–195, DOI: https://doi.org/ 10.6001/energetika.v64i4.3893. 9. Kustov M.V., Kalugin V.D., Tutunik V.V., Tarakhno O.V. (2019), "Physicochemical principles of the technology of modified pyrotechnic compositions to reduce the chemical pollution of the atmosphere", Voprosy Khimii i Khimicheskoi Tekhnologii, No. 1 (2019), pp. 92–99, DOI: 10.32434/0321-4095-2019-122-1-92-99. 10. Pospelov B., Rybka E., Meleshchenko R., Gornostal S., Shcherbak S. (2017), "Results of experimental research into correlations between hazardous factors of ignition of materials in premises", EasternEuropean Journal of Enterprise Technologies, Vol. 6 (10-90), pp. 50-56, DOI: 10.15587/1729-4061.2017. 117789. 11. Pospelov B., Rybka E., Meleshchenko R., Borodych P., Gornostal S. (2019), "Development of the method for rapid detection of hazardous atmospheric pollution of cities with the help of recurrence measures", Eastern-European Journal of Enterprise Technologies, Vol. 1, No 10 (97), pp. 29–35, DOI: doi.org/10.15587/1729-4061.2019.155027. 12. Pospelov B., Andronov V., Rybka E., Skliarov S. (2017), "Research into dynamics of setting the threshold and a probability of ignition detection by selfadjusting fire detectors", EasternEuropean Journal of Enterprise Technologies, Vol. 5 (9-89), pp. 43–48, DOI: 10.15587/1729-4061.2017.110092. 13. Kanilo P.M., Bey I.S., Rovensky O.I. (2000), "Automobile and environment", Kharkiv, Publ. Prapor, 304 p. 14. Shvedun V.O. (2015), "Experience of EU countries in ensuring public administration of advertising activity", Actual Problems of Economics, Vol. 168 (6), art. no. A084, pp. 84–90. 15. Efros V.V. at al. (1976), "Diesel engines with air cooling of Vladimir tractor plant", Moscow, Publ. Mashinistroyeniye, 277 p. 16. Uniform provision concerning the approval of compression ignition (C.I.) and natural gas (NG) engines as well as positive-ignition (P.I.) engines fuelled with liquefied petroleum gas (LPG) and vehicles equipped with C.I. and NG engines and P.I. engines fuelled with LPG, with regard to the emissions of pollutants by the engine: regulation United Nations Economic and Social Council Economics Commission for Europe Inland Transport Committee Working Party on the Construction of Vehicles of 26 January 2013 year Regulation No. 49, Revision 6 [Electronic recourse]. – Geneva: UNECE, 2013. – 434 p. – URL: https://www.unece.org/fileadmin/DAM/trans/main/ wp29/wp29regs/2013/R049r6e.pdf. 17. Sigal I.Ya., Slavin V.I., Shylo V.V. (1999). "Purification of industrial emissions from sulfur and nitrogen oxides", Kharkiv, Publ. Original, 142 p. 18. Guidelines for the transfer of boilers operating on sour liquid fuels in the combustion mode with extremely small excesses of air (1980), Moscow, Publ. Soyuztechenergo, 34 p. 19. GOST 32511-2013 "Diesel fuel EURO. Technical conditions" (2014), Moscow, Publ. Standartinform, 19 p. 20. GOST 32511-2013 "Ship fuel. Technical conditions" (2012), Moscow, Publ. Standartinform, 36 p. 21. GOST 305-82 "Diesel fuel. Technical conditions" (2009), Moscow, Publ. Standartinform, 22 p. 22. GOST 2084-77 "Diesel fuel. Technical conditions" (2006), Moscow, Publ. MPK Izd-vo standartov, 9 p. 23. GOST R 51866-2002 "Motor fuels. Unleaded gasoline. Technical conditions" (2009), Moscow, Publ. Standartinform, 43 p. 24. GOST 12337-84 "Motor oils for diesel engines. Technical conditions" (2002), Moscow, Publ. MPK Izd-vo standartov, 12 p. 25. GOST 33305-2015 "Lubricating oils. Method for determination of phosphorus, sulfur, calcium and

zinc by energy dispersive x-ray fluorescence spectroscopy" (2016), Moscow, Publ. Standartinform, 11 p. 26. Anisimov I.G., Badyshtova K.M., Bnatov S.A. (1999), "Fuels, lubricants, technical fluids. Assortment and Application: Reference book", Moscow, Publ. center "Techinform", 596 p. 27. Engine oil consumption rates for operational needs of stationary diesel power plants RD 34.10.563-94 (1997), Moscow, Publ. ORGRES, 7 p. 28. R 3112194-0366-03. New standards for the consumption of fuels and lubricants in road transport (2003), Moscow, Publ. INFRA-M, 50 p. 29. Perevozchikov A.M. at al. (2006), "Motorcycles IZh Planeta and IZh Jupiter of the 4th and 5th generations. Repair and maintenance manual", Moscow, Publ. ATLAS-PRESS, 256 p. 30. Kondratenko, O.M., Strokov, O.P., Vambol, S.O., Avramenko A. M, (2015), "Mathematical model of efficiency of diesel particulate matter filter", Scientific Bulletin of NMU, Issue 6 (150), pp. 55–61, URL: http://repositsc.nuczu.edu.ua/handle/ 123456789/2227. 31. Vambol, S., Vambol, V., Kondratenko, O., Suchikova, Y., Hurenko, O. (2017), "Assessment of improvement of ecological safety of power plants by arrangement of pollutants neutralization system", Eastern-European Journal of Enterprise Technologies, № 3/10 (87), pp. 63–73, URL: http://journals.uran.ua/eejet/ article/viewFile/ 102314/100169. 32. Kondratenko, O., Mishchenko, I., Chernobay G., Derkach, Yu., SuchikovaYa. (2018), "Criteria based assessment of the level of ecological safety of exploitation of electric generating power plant that consumes biofuels", Book of Papers of 2018 IEEE 3rd International International Conference on Intelligent Energy and Power Systems (IEPS–2018), 10–14 September, Kharkiv, Publ. NTU "KhPI", pp. 185–189. URL: www.ieps. org.ua, DOI: 10.1109/ IEPS.2018.8559570. 33. Strokov O.P., Kondratenko O.M., Koloskov V.Yu., Mishchenko I.V. (2019), "Description of mass hourly emissions of particulate matter of diesel engine by beta-distribution with taking into account the passport accuracy of gas analyzer", Internal combustion engines, № 1, pp. 49–62, DOI: 10.20998/0419-8719.2019.1.09. 34. Kondratenko O.M., Chernobay G.O., Derkach Ju.F., Kovalenko S.A. (2019), "Features of determination of the efficiency of devices for improvement of ecological safety level of vehicles with reciprocating ICE exploitation", Internal combustion engines, № 2, pp. 36–44, DOI: 10.20998/0419-8719. 2019.2.07.

Received to the editorial office 10.06.2020

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.

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.

Derkach Yuriy Fedorovych – Cand. Sc.(Phys.-Math.), Senior Researcher, Lecturer of Applied Mechanics and Environment Protection Technologies Dept., National University of Civil Defence of Ukraine, Kharkiv, Ukraine. e-mail: dyf1935@gmail.com, ORCID ID: 0000-0003-2638-8907; Google Scholar ID: uDK1tN0AAAAJ.

Kovalenko Svitlana Andriivna – Master Sc., Lecturer of Applied Mechanics and Environment Protection Technologies Dept., National University of Civil Defence of Ukraine, Kharkiv, Ukraine. e-mail: pro100sveta.kovalenko@gmail.com, ORCID ID: 0000-0003-2323-0856; Google Scholar ID: ZPgjdZsAAAAJ.

КРИТЕРІАЛЬНЕ ОЦІНЮВАННЯ ПАЛИВНО-ЕКОЛОГІЧНОЇ ЕФЕКТИВНОСТІ ПРОЦЕСУ ЕКСПЛУАТАЦІЇ ПОРШНЕВОГО ДВЗ ЕНЕРГОУСТАНОВКОК З ВРАХУВАННЯМ ВИКИДІВ ОКСИДІВ СІРКИ

Кондратенко О. М., Колосков В. Ю., Деркач Ю. Ф., Коваленко С. А.

В даному дослідженні вдосконалено методику розрахунку і математичний апарат для оцінки значень комплексного паливно-екологічного критерію проф. Ігоря Парсаданова шляхом врахування годинних масових викидів оксидів сірки з потоком відпрацьованих газів поршневого ДВЗ як токсичного полютанта. Метою дослідження є отримання величин комплексного паливно-екологічного критерію, які характеризують рівень екологічної безпеки процесу експлуатації дизельних двигунів з урахуванням викидів оксидів сірки як токсичного полютанту. Випробувальний цикл European Steady Cycle (відповідно до Правил ЄЕК ООН № 49) використовувався в якості моделі експлуатації. Отримано набір вихідних даних для розрахункового критеріального оцінювання рівня екологічної безпеки процесу експлуатації енергоустановок з поршневим ДВЗ на прикладі автотракторного дизеля 2Ч10,5/12 за результатами обробки даних стендових моторних випробувань. Розрахункова оцінка значень зазначеного критерію проводилася з урахуванням викидів оксидів сірки. Виявлено, що значення паливно-екологічного критерію для базового варіанту з урахуванням викидів оксидів сірки, тобто з урахуванням значень вмісту сірки в моторних паливах і оливах та втрати оливи на чад, характерних для дизеля 2Ч10,5/12, відрізняється для варіанту, який не враховує цей фактор екологічної безпеки, в середньому на 6,6 %. Для варіанту, який враховує сучасні вимоги до вмісту сірки в технічних рідинах і технічному рівню сучасного поршневого ДВЗ, ця різниця становить 0,5 %. Виявлені залежності описано формулами методом найменших квадратів. Наукова новизна отриманих результатів у тому, що отримав подальшого розвитку підхід проф. Ігоря Парсаданова щодо критеріїв оцінювання паливно-екологічної ефективності процесу експлуатації автотракторних дизельних двигунів як частини енергоустановки з урахуванням масових годинних викидів оксидів сірки з потоком відпраьованих газів поршневого ДВЗ як токсичного полютанту, а також методика визначення таких викидів та їх вагомості у напрямку застосування цього математичного апарату для стандартизованих стаціонарних випробувальних циклів.

Ключові слова: технології захисту навколишнього середовища, екологічна безпека, енергетичні установки, двигуни внутрішнього згоряння, викид оксидів сірки, полютанти.

КРИТЕРИАЛЬНОЕ ОЦЕНИВАНИЕ ТОПЛИВО-ЭКОЛОГИЧЕСКОЙ ЭФФЕКТИВНОСТИ ПРОЦЕССА ЭКСПЛУАТАЦИИ ПОРШНЕВОГО ДВС ЭНЕРГОУСТАНОВКИ С УЧЕТОМ ВЫБРОСОВ ОКСИДОВ СЕРЫ

Кондратенко А. Н., Колосков В. Ю., Деркач Ю. Ф., Коваленко С. А.

В данном исследовании усовершенствованы методика расчета и математический аппарат для оценки значений комплексного топливно-экологического критерия проф. Игоря Парсаданова путем учета часовых массовых выбросов оксидов серы с потоком отработавших газов поршневого ДВС как токсичного поллютанта. Целью исследования является получение величин комплексного топливно-экологического критерия, характеризующих уровень экологической безопасности процесса эксплуатации дизельных двигателей с учетом выбросов оксидов серы как токсичного полютанта. Испытательный цикл European Steady Cycle (в соответствии с Правилами ЕЭК ООН № 49) использовался в качестве модели эксплуатации. Получен набор исходных данных для расчетной критериальной оценки уровня экологической безопасности процесса эксплуатации энергоустановок с поршневым ДВС на примере автотракторного дизеля 2Ч10,5/12 по результатам обработки данныех стендовых моторных испытаний. Расчетная оценка значений указанного критерия проводилась с учетом выбросов оксидов серы. Выявлено, что значение топливно-экологического критерия для базового варианта с учетом выбросов оксидов серы, т.е. с учетом значений содержания серы в моторных топливах и маслах и расхода масла на угар, характерных для дизеля 2Ч10,5/12, отличается для варианта, который не учитывает этот фактор экологической безопасности, в среднем на 6,6 %. Для варианта, который учитывает современные требования к содержанию серы в технических жидкостях и техническому уровню современного поршневого ДВС, эта разница составляет 0,5 %. Выявленные зависимости описаны формулами методом наименьших квадратов. Научная новизна полученных результатов заключается в том, что получил дальнейшее развитие подход проф. Игоря Парсаданова к критериальному оцениванию топливно-экологической эффективности процесса эксплуатации автотракторных дизельных двигателей как части энергоустановки с учетом массовых часовых выбросов оксидов серы с потоком отработавших газов поршневого ДВС как токсичного полютанта, а также в разработке методики определения таких выбросов и их весомости в направлении применения этого математического аппарата для стандартизированных стационарных испытательных циклов.

Ключевые слова: технологии защиты окружающей среды, экологическая безопасность, энергетические установки, двигатели внутреннего сгорания, выброс оксидов серы, поллютанты.