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ACCOUNTING FOR THE HARMFUL EFFECT OF CARBON DIOXIDE IN COMPREHENSIVE ASSESSMENT OF FUEL CONSUMPTION AND EXHAUST GASES TOXICITY DIESEL ENGINES

I.V. Parsadanov, I.V. Rykova

Over the past decades, research into combustion processes in internal combustion engines, additional processing of exhaust gases has led to a reduction in harmful emissions (nitrogen oxide NO_x, unburned hydrocarbons C_nH_m, carbon monoxide CO and particulate matter). However, personal concern among scientists and the international community is caused by the increase in CO_2 carbon dioxide emissions into the environment during the operation of power plants, which contributes to the increase of the "greenhouse effect". In order to determine effective technical solutions for improving diesel engines with the aim of reducing fuel consumption and emissions of harmful substances with exhaust gases, the Department of Internal Combustion Engines of the National Technical University "Kharkiv Polytechnic Institute" proposed a dimensionless complex criterion of fuel economy and exhaust gas toxicity, which provides information on the economic and environmental perfection of diesel engines. However, this criterion does not take into account the environmental impact of CO_2 emissions. The work considers the conditions for taking into account the harmful effects of CO_2 using the method of comprehensive assessment of fuel consumption and exhaust gas toxicity. The mass emission of CO_2 for each mode of diesel operation is determined if the elemental composition of the fuel, its molecular weight, heat of combustion and consumption, composition and consumption of air, as well as environmental parameters are known. In order to provide an objective assessment of the effect of CO_2 emitted from HG diesels on humans and the environment, it is necessary to introduce appropriate corrections that characterize its relative aggressiveness indicator. First of all, this is a correction that takes into account the effect of CO_2 on various recipients, in addition to humans, and a correction that takes into account the possibility of accumulation of the substance in the components of the environment and in food chains, as well as its entry into the human body by non-inhalation. An objective scientific approach is necessary for the justification and implementation of the introduction of such amendments, which takes into account all the components of determining the negative impact of CO_2 on humans and the environment: the greenhouse effect, climate change both in terms of direct impact and in the long-term perspective.

Keywords: carbon dioxide; fuel and ecological criterion; fuel consumption; toxicity of exhaust gases

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ACCOUNTING THE EMISSIONS OF ENGINE FUEL VAPORS IN THE CRITERIA-BASED ASSESSMENT OF THE ECOLOGICAL SAFETY LEVEL OF POWER PLANTS WITH RECIPROCATING ICE EXPLOITATION PROCESS

This study proposed the approach and method on its basis for carrying out of the calculated assessment of the values of the comprehensive fuel and environmental criterion of Prof. I. Parsadanov as the indicator of the ecological safety level of the exploitation process of power plants with diesel reciprocating internal combustion engine, considering the mass hourly emissions of engine fuel vapor caused by the phenomena of large and small breathing of reservoirs. The purpose of the study is to develop the method for taking into account the parameters of pollutant emissions into the environment, such as motor fuel vapors due to the phenomena of large and small breathing of the power plant fuel tanks, as an independent factor of ecological safety. The calculated assessment according to the proposed method is carried out considering the properties of engine fuel, degree of a fuel tank filling, features of model of the engine operation, daily difference of atmospheric air temperature and settings of the respiratory valve of the tank. It is found that considering the emission of engine fuel vapors caused by the phenomenon of small breathing has almost no effect on the level of environmental safety, but for the option of taking into account the effect of the phenomenon of large breathing, such an effect is significant. The scientific novelty of the obtained results is that for the first time a method for considering the emission of engine fuel vapors caused by large and small breathing of fuel tanks of reciprocating internal combustion engines in complex criteria-based assessment of ecological safety. The practical value of the obtained results is that they are suitable for quantitative and qualitative assessment of the studied effects and development on this basis of technical solutions and organizational measures to reduce or eliminate them by developing appropriate environmental protection technology with actuators on a methodological basis of environmental safety management system, including the use of other steady standardized testing cycles as models of engine operation.

Key words: *environment protection technologies; ecological safety; power plants; internal combustion engines; criteria-based assessment; emission of fuel vapor; large reservoire breathing;small reservoire breathing.*

Relevance of the study and problem statement

In order to provide a complex assessment of the values of ecological safety (ES) indicators of the exploitation process of power plants (PP) with diesel reciprocating internal combustion engines (RICE) [1], equipped with fuel tanks, which are essentially reusable containers (tanks) for storage of chemically active, flammable and explosive, toxic fluids, so it is advisable to use the mathematical apparatus of the complex fuel-ecological criteria of Prof. I. Parsadanov K_{fe} (NTU «KhPI»), described in the monograph [2] and improved in the monograph [1].

In the study [1] the environmental protection technology (EPT) from the negative antropogenic impact of RICE in PP during its exploitation was developed. Such EPT is based, inter alia, on the improved hierarchical classification of ES factors, the source of which is such a technical object. In addition to emissions of legislative normalized pollutants with exhaust gas (EG) flow, the classifier also includes consumption of motor fuel as a non-renewable energy resource (mineral source processing product), as well as emissions of motor fuel vapors due to the manifestations of small (SRB) and large (LRB) reservoire breathing, namely fuel tanks of PP.

However, in the structure of ES factors taken into account by the original mathematical apparatus of the K_{fe} criterion, the first of these factors is taken into account indirectly, and the second is not taken into account at all. The developed approaches to determining the ponderability of fuel consumption of RICE as the ES factor were used to study the application of the K_{fe} criterion as a separate independent ES factor in the structure of a new criterion based on the mathematical apparatus of Harrington's generalized desirability function [3]. These results were also applied to the cases of fuel and ecological efficiency assessment of RICE conversion to the consumption of motor fuels of biological origin in [4–6], taking into account the properties of this type of alternative fuel obtained in studies [7,8]. Taking into account this ES factor in combination with the existing fully corresponds to the concept of improving the mathematical apparatus of the K_{fe} criterion, developed in [1], the general provisions [9–12] of RICE and oil and fuel delivery process ecologisation, as well as the main trends in technogenic and ecological safety of enterprises for production, refining, storage and distribution of petroleum products [13].

It is also known that reusable containers (reservoirs) for chemically active, flammable and explosive, toxic fluid, which are subject to weight and inertial mechanical loads that are permanent, pulsed or oscillating, is a product of high-tech production and has a high cost [14]. Exploitation of ground-based vehicles fuel tanks is always accompanied by emissions of motor fuel vapors caused by the manifestations of SBR and LBR. This leads, firstly, to the waste of valuable and scarce energy resources, and secondly, to air pollution by hydrocarbons [15–17].

It also should be noted that RICE is a powerful source of environmental pollution by various physical factors, including non-renewable energy sources (motor 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 develop the method for taking into account the parameters of pollutant emissions into the environment, such as motor fuel vapors due to the phenomena of large and small breathing of of fuel tanks of the power plant, as an independent ES factor.

Problem of the study is to determine the effects of taking into account the emission of motor fuel vapors due to the phenomena of SBR and LBR of PP with RICE fuel tanks, in a complex criteria-based assessment of the ES level of exploitation of such facilities on the ESC steady standardized testing cycle (according to UNECE Regulation 49 [18, 21]) on the basis of the improved mathematical apparatus of the complex fuel-ecological criterion. **Object of the study** is the ES of the PP with RICE exploitation process, on board of which motor fuel is stored. **Subject of the study** is the contribution to the indicators of the object of the study of motor fuel vapor emission caused by the phenomena of LBR and SBR of fuel tanks of PP with RICE. The study was performed on the example of autotractor diesel engine D21A1 (2Ch10.5/12 in accordance with ISO 3046-1:2002 [19]). **Methods of the study.** Analysis of specialized scientific and technical, normative, patent and reference literature, analysis of data of bench motor tests on standardized steady test cycles, basics of the scientific discipline «Theory of RICE», 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 for the calculated assessment of the values of the complex fuel-ecological criterion with taking into account the emissions of motor fuel vapors due to the phenomena of LRB and SRB of PP fuel tanks with RICE. 2. Obtaining the initial data set for the calculation study for the ESC standardized steady testing cycle and 2Ch10.5/12 autotractor diesel engine. 3. Calculated assessment of the values of the complex fuel-ecological criterion taking into account the emissions of motor fuel vapors caused by the phenomena of LRB and SRB of PP with RICE fuel tanks and analysis of its results.

Scientific novelty of the obtained results. *For the* *first time* the method for taking into account the emission of motor fuel vapors caused by large and small breathing of fuel tanks of reciprocating internal combustion engines in complex criteria-based assessment of ecological safety.

Practical value of the obtained results. Method based on the proposed approache for the calculated assessment are *suitable* for quantitative and qualitative assessment of the studied effects and development on this basis of technical solutions and organizational measures to reduce or eliminate them by developing appropriate environmental protection technology with executive bodies on a methodological basis of environmental safety management system (ESMS), including the use of other stesdy standardized testing cycles as models of engine exploitation.

1. Method of calculated assessment of values of complex fuel-ecological criterion with taking into account emissions of motor fuel vapors caused by phenomena of large and small breathing of fuel tank of power plant

It is a well-known fact that the storage of motor fuels, both separately and on board the PP with RICE, is accompanied by negative effects of emissions of motor fuel vapors into the atmospheric air by the mechanisms of LRB and SRB [15–17].

LRB for fuel tank is a phenomenon of emission of motor fuel vapors into the atmospheric air, which has a volley character, which is caused by displacement of gaseous fluid from the tank by dripping liquid at its full or partial filling (refueling) through regulated or unregulated shut-off valve.

SRB for fuel tank is a phenomenon of emission of motor fuel vapors into the atmospheric air, which has a volley character, which is due to cyclical changes in temperature (daily fluctuations of air temperature and barometric pressure) during operation of the PP with RICE or tank, which causes alternating evaporation and condensation of liquid motor fuel and the corresponding change in the value of the pressure of its saturated vapors in the tank, the lack and excess of which is compensated by mass exchange with environment air through the adjusted two-way valve in the shut-off body of the tank.

In general, losses of petroleum products during their storage in tanks are divided into the following [14–17]: a) from leaks in leaky housings and loosely closed shut-off bodies of tanks and their pipelines and fittings b) from mixing different types and grades of petroleum products in the same tank during alternating refueling; c) from evaporation when expelled to atmospheric air vapor-air mixture. The phenomena of LRB and SRB are types of loss of petroleum products during their storage in tanks by evaporation. Such losses also include: a) from tank ventilation and ejection of fuel vapor; b) from the saturation of air over the free surface of the oil product with its vapor. Therefore, since the phenomena of LBR and SBR are accompanied by mass hourly emission motor fuel vapors from PP with RICE during its exploitation, it is possible and appropriate to develop a methodology and implement on its basis the calculated assessment of ES level of this process using improved mathematical apparatus of complex fuel-ecological criterion K_{fe}.

1.1 Analysis of the criterion mathematical apparatus

The value of the K_{fe} criterion for the *i*-th steady regime of RICE operation with the value of the weight factor *WF* is determined by formula (1.1) [1,2], and the place in it of mass hourly emissions of motor fuel vapors caused by LRB and SRB, in this paper proposed by formula (1.2).

$$K_{fe} = (3600 \cdot N_e)/(H_u \cdot G_{fuel}) \times \\ \times G_{fuel} \cdot 10^3 \Big/ \left(G_{fuel} + \sigma \cdot f \cdot \sum_{m=1}^{h} (A_k \cdot G_k) \right), \text{‰}, \quad (1.1)$$

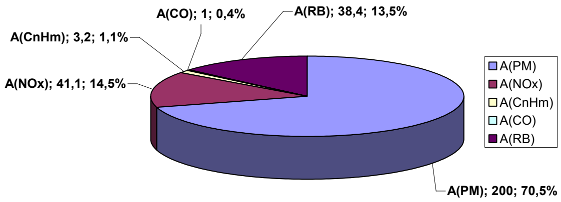
$$\begin{aligned} \sum_{m=1}^{h} (A_k \cdot G_k) &= A(PM) \cdot G(PM) + \\ &+ A(NO_x) \cdot G(NO_x) + \\ &+ A(C_nH_m) \cdot G(C_nH_m) + \\ &+ A(CO) \cdot G(CO) + A(RB) \cdot G(RB) \end{aligned}, \text{ kg/h}, \quad (1.2)$$

where N_e – the RICE effective power, kW; G_{fuel} – mass hourly fuel consumption, kg/h; H_u – lower heat of combustion of motor fuel, MJ/kg; G_k – mass hourly emission of the *k*-th pollutant component of EG, kg/h; A_k – dimensionless indicator of the relative aggressiveness of the *k*-th pollutant component of EG; *h* – total number of legally regulated polluting components in EG; σ – dimensionless indicator of the relative risk of pollution in different areas; *f* – dimensionless coefficient that takes into account the nature of EG scattering in the atmosphere.

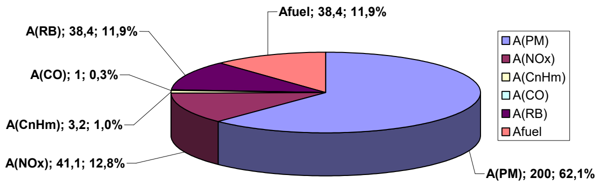
1.2 Method of determining the value of motor fuel vapor emissions and taking into account this factor of ecological safety in a complex criteria-based assessment

As mentioned above, to implement the solution of the scientific and technical problem, it is proposed to introduce into the structure of formula (1.2) as a component of formula (1.1) the component *G*(RB)·*A*(RB), which is the product of mass hourly emissions of motor fuel due to LRB and SRB *G*(RB) and dimensionless indicator of relative aggressiveness of motor fuel vapor *A*(RB).

As the value of *A*(RB) is proposed to use the value of the ponderability of the fuel component of the K_{fe} criterion, averaged over the entire field of operational regimes of 2Ch10.5/12autotractor diesel engine, defined in previous studies by equating expressions for partial derivatives of K_{fe} by G_{fuel} and G_k. Then we take A(RB) = A_{fuel} = 38.4. Then the diagram of the share contribution of the ponderability of emission of motor fuel vapors has the form shown in Fig. 1.



a)



b)

Fig. 1. Share contribution of A(RB) to the structure of the ponderability of ES factors in the mathematical apparatus of the K_{fe} criterion without taking into account the ponderability of fuel consumption (a) and with taking it into account (b)

The value of the emission G(RB) is proposed to be defined as the sum of the emission at LRB G(SB) and the emission at SRB G(IB) of the tank by formula (1.3). The mass hourly emission G(SB) is determined by formula (1.4).

$$G(\mathrm{RB}) = G(\mathrm{SB}) + G(\mathrm{IB}),\ \mathrm{kg/h}, \qquad (1.3)$$

$$G(\mathrm{SB}) = M(\mathrm{SB}) / \tau_{SB}\ ,\ \mathrm{kg/h}, \qquad (1.4)$$

where M(SB) – mass of volley emissions of motor fuel vapor, kg; τ_{SB} – time between volleys of emissions, h.

The method based on the following assumptions has been developed to determine the G(SB) emission values: a) the PP fuel tank equipped with the studied RICE is refueled with a new portion only after full consumption of motor fuel; b) the volume of the portion of fuel when refueling the fuel tank corresponds to its full volume; c) the regime of operation of the PP with RICE is variable, the duration of the shift is 8 hours without a break, for the day the PP operates 1 (8 hours), 1.5 (12 hours), 2 (16 hours) or 3 (24 hours) shifts; d) the model of exploitation of such PP is ESC steady standardized testing cycle, containing 13 steady-state regimes of operation; e) during the operation of the PP there are no significant fluctuations in temperature and humidity, barometric pressure and other meteorological parameters; e) when emptying the fuel tank and filling it with a new portion of motor fuel, its vapors does not mix with atmospheric air, i.e. the emission consists exclusively of fuel vapor and does not contain air; g) the velocity of the fluid in the processes of both emptying and filling the fuel tank is negligible.

The fuel tank of the T-25 tractor equipped with a 2Ch10.5/12 diesel engine can contain up to 45 liters of liquid fuel [9,22]. Taking into account the following accepted assumptions, we will be impressed that at full refueling of the fuel tank of such PP the volume of motor fuel vapors V(SB) is equal to the volume of the fuel tank, i.e. V(SB) = $4{,}5\cdot10^{-2}$ m^3. In this case, taking into account that the molar mass of diesel fuel grade «3» μ_{fuel} = 172.3 g/mol [23], and the process itself takes place at a pressure equal to normal atmospheric magnitude p_0 = 101325 Pa, and the atmospheric air temperature t_0 = 300 K (27 °C), the mass of the volley emission M(SB) of fuel vapor will be 0.314 kg at the vapor density of fuel in the tank ρ = 6.978 kg/m^3.

The duration of the period of time between volleys of fuel vapor emission τ_{SB} can be determined by the regime values of the time of consumption of the entire fuel tank of the PP with RICE τ_{ff}, parameters of the DPA operation model and data on the EU operation mode equipped with this SEA. The value of the duration of the period τ_{ff} for a single RICE steady regime of operation is determined by formula (1.5).

$$\tau_{ff} = M_{fuel} / G_{fuel},\ \mathrm{h}, \qquad (1.5)$$

where M_{fuel} – mass of fuel in a fully filled PP fuel tank, kg; G_{fuel} – RICE mass hourly fuel consumption, kg/h.

The value of mass M_{fuel} is 38.25 kg at a density of liquid motor fuel ρ_{fuel} = 850 kg/m^3 under normal conditions [17]. The distribution of the values of the value of τ_{ff} in the field of operating regimes of the 2Ch10.5/12 diesel engine is shown in Fig. 2,a. It shows that the average value of τ_{ff} in this field is 23.019 hours. Then the amount of emission G(SB) is determined by formula (1.6).

$$G(\mathrm{SB}) = M(\mathrm{SB}) / \tau_{ff} = G_{fuel} \cdot M(\mathrm{SB}) / M_{fuel} = G_{fuel} \cdot 8.209\cdot10^{-3},\ \mathrm{kg/h}. \qquad (1.6)$$

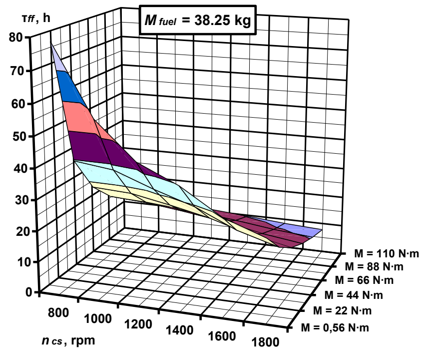
The consumption time per unit mass (1 kg) of diesel fuel by the 2Ch10.5/12 diesel engine τ_{f1} is determined by formula (1.7).

$$\tau_{f1} = 1 / G_{fuel},\ \mathrm{h}. \qquad (1.7)$$

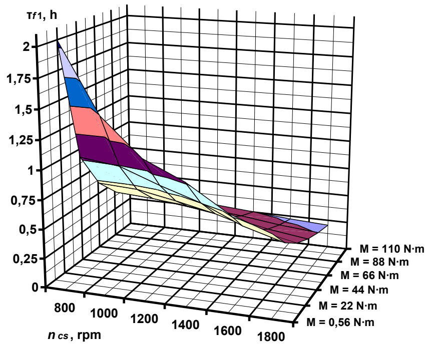
The distribution of values of time τ_{f1} in the field of operating regimes of the 2Ch10.5/12 diesel engine is shown in Fig. 2,b. This figure shows that the average value of τ_{f1} in this field is 0.602 hours.

The distribution of emission values G(SB) and G(IB) on the field of of operating regimes of the diesel engine 2Ch10.5/12 is shown in Fig. 2,c and Fig. 2,d. It shows that the average value of G(SB) in this field is 0.018 kg/h and such value of G(SB) is 0.0011 kg/h.

Graph of the dependence of the total average (on the field of operating regimes), maximum (nominal effective power regime) and minimum (minimum idling regime) mass emission of fuel vapors on the LRB mechanism for 1 working day the source of which is the PP with the 2Ch10.5/12 diesel engine, M_Σ(SB) from the duration of the working shift τ_W is shown in Fig. 3.



a)



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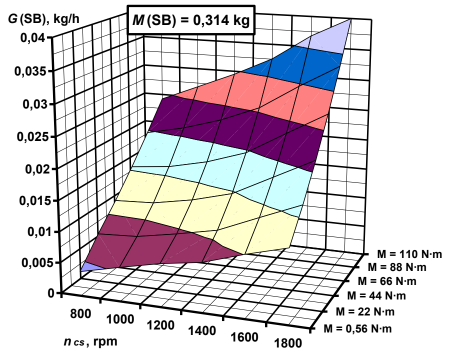

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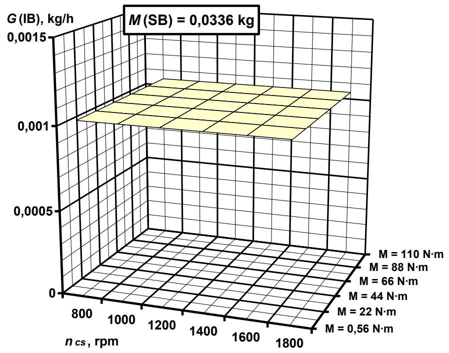

d)

Fig. 2. Distributions of magnitudes of value τ_{ff} (a), value τ_{f1} (b), values of emission G(SB) (c), emission G(IB) (d) on the field of operating regimes of the 2Ch10.5/12 autotractor diesel engine

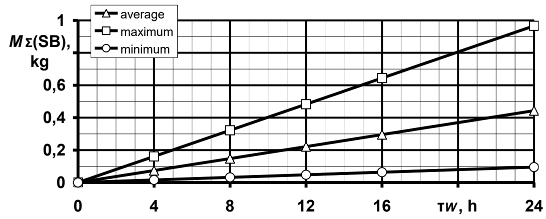

Fig. 3. Graph of the dependence of the total daily mass emission M_Σ(SB) on the duration of the working shift τ_W of PP with 2Ch10.5/12 diesel engine

To determine the values of the mass hourly emission of motor fuel vapor emitted by the phenomenon of SRB, *G*(IB), the following method is proposed according to which the emission value of *G*(IB) will be determined by formula (1.8).

$$G(\text{IB}) = M(\text{IB}) / \tau_{IB},\ \text{kg/h}, \qquad (1.8)$$

where *M*(IB) – mass of volley emissions of motor fuel, kg; τ_{IB} – duration of the period of time between volleys of emissions, h.

Given that the main driving force of the emission of motor fuel vapors in the SRB phenomena in the PP is the daily air temperature difference Δt_0, and the emission leads to its increase, which occurs once a day, then the time τ_{IB} will be 1 day, i.e. 24 hours.

The mass of fuel vapor emission *M*(IB) is defined as the sum of two values, one of which is due to the increase in saturated vapor pressure of motor fuel M_f(IB), and the second is due to increase in gaseous pressure in the isochoric process when heated M_t(IB), i.e. by formula (1.9).

$$M(\text{IB}) = M_f(\text{IB}) + M_t(\text{IB}),\ \text{kg}. \qquad (1.9)$$

According to the official information server of the Kharkiv Regional Center for Hydrometeorology [24] and the independent Internet resource Meteopost [25], the largest diurnal temperature differences on the planet are areas with a sharply continental climate, including deserts. In summer, the air temperature in the Sahara desert reaches 50 °C during the day (and solids up to 70 °C under direct sunlight), and drops to 0 °C at night. For the city of Kharkiv, according to the source [25] for 2018, the following data were obtained (see Fig. 4): the highest average monthly temperature during the day is observed in August (+29.9 °C), the lowest – in February (–2.6 °C); the highest average monthly temperature at night is observed in July (+17.7 °C), the lowest – in February (–7.0 °C); the average annual value of the average monthly temperature during the day is +13.4 °C, and at night – +4.7 °C; the average daily temperature difference during the year ranges from +2.3 °C (December) to +14.0 °C (August), and its average annual value is +8.6 °C. Thus, the daily difference in air temperature in Kharkiv during the year does not exceed 15 °C, and on some days it reaches extreme values of 0 °C and 20 °C.

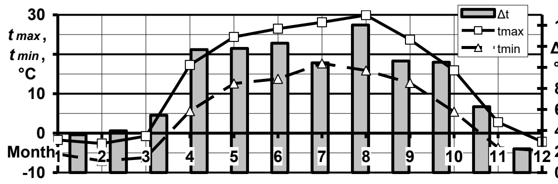

Fig. 4. Distribution of values of average monthly air temperature and daily temperature difference in Kharkiv for 2018 by months of the year

The value of the mass of vapor emission M_f(IB) is proposed to be obtained from the analysis of the equation of state of an ideal gas (formula (1.10)), namely from formula (1.11).

$$M_f(\text{IB}) = \partial m_f(\text{IB}) / \partial p_{fv} \cdot \Delta p_{fv}, \text{ kg}, \quad (1.10)$$

$$m_f(\text{IB}) = \mu_{fuel} \cdot p_{fv} \cdot V_{fv} / (R \cdot T_{fv}), \text{ kg}, \quad (1.11)$$

$$\partial m_f(\text{IB}) / \partial p_{fv} = \mu_{fuel} \cdot V_{fv} / (R \cdot T_{fv}) = = 0{,}0207 \cdot V_{fv} / T_{fv}, \text{ kg/Pa}, \quad (1.12)$$

$$\Delta p_{fv} = p_0 + p_{нп}, \text{ Pa}, \quad (1.13)$$

$$p_{нп} = \exp(((T_{fv} - 273) - 2{,}5) / 53{,}439), \text{ Pa}, \quad (1.14)$$

where μ_{fuel} = 172.3 g/mol [23] – molar mass of fuel vapor; p_{fv} – fuel vapor pressure in the fuel tank, Pa; V_{fv} – volume of fuel vapor in the fuel tank, m^3; R = 8,314 J/(mol·K) – universal gas constant; T_{fv} – fuel vapor temperature in the fuel tank, K; p_0 = 101325 Pa – barometric pressure; $p_{np} = f(T_{fv})$ is the saturated vapor pressure of the fuel at a given temperature (see [26]), Pa.

The following parameters of influencing factors were considered in this study: a) T_{fv} = 0…50 °C, i.e. ΔT_{fv} = [5, 15, 50] °C; b) V_{fv} = [1/4, 1/2, 3/4]·V_{ft}, V_{fv} = 45 l – volume of the fuel tank, i.e. V_{fv} = [11.25, 22.5, 33.75] l; c) the basic values of the influencing factors are: ΔT_{fv} = 15 °C, V_{fv} = 1/2·V_{ft} = 22.5 l.

The dependence $p_{np} = f(T_{fv})$ for diesel fuel is contained in Fig. 5. The dependence of the values of the mass of diesel fuel vapor in the fuel tank of PP on the degree of filling the tank with liquid fuel for the initial conditions is illustrated in Fig. 6. Graphs of the dependence of the values of the mass gain and mass of vapor of diesel fuel in the fuel tank on its temperature for different degrees of filling the tank with liquid fuel are shown in Fig. 7. In Fig. 7 shows that such dependences are almost linear and significantly different for different degrees of filling the tank with fuel.

The increase in the pressure of the gaseous fluid in the fuel tank of PP, due to the heating of the fuel vapor is determined by formula (1.15).

$$p_{fv} = m_t(\text{IB}) \cdot R \cdot T_{fv} / (\mu_{fuel} \cdot V_{fv}) = = 48{,}253 \cdot m_t(\text{IB}) \cdot T_{fv} / V_{fv}, \text{ Pa}. \quad (1.15)$$

In Fig. 8 is a graph of the dependence of the values of the diesel fuel vapor pressure in the PP fuel tank on the degree of filling the tank with liquid fuel for the initial conditions Fig. 8 shows that these dependences are almost linear.

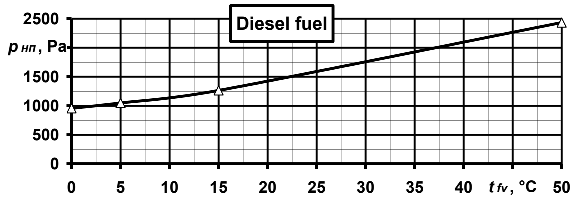

Fig. 5. Graph of dependence of saturated vapor pressure of diesel fuel on its temperature

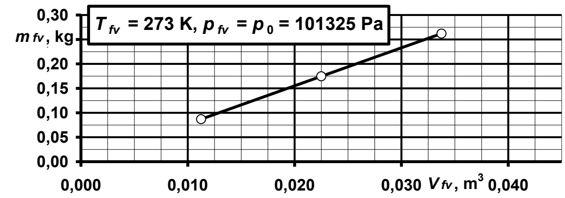

Fig. 6. Graph of dependence of values of mass of diesel fuel vapors in the fuel tank of PP on the degree of filling tank with liquid fuel for the initial conditions

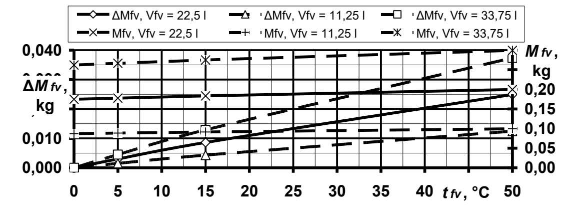

Fig. 7. Graphs of dependence of values of mass and gaine of mass of vapors of diesel fuel in the fuel tank of PP on its temperature for various degrees of filling of a tank with liquid fuel

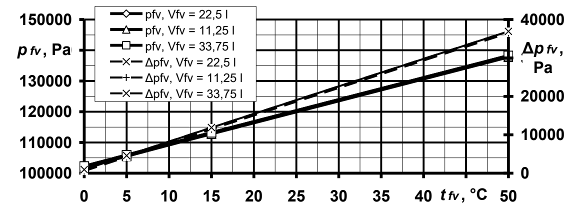

Fig. 8. Graphs of dependence of the values of the pressure gain and vapor pressure of diesel fuel in the PP fuel tank on its temperature for different degrees of filling the tank with liquid fuel

The value of the excess pressure of the gaseous fluid in the PP fuel tank, which is set to the shut-off valve for the tractor T-25 p_{valve} is 15 kPa and vacuum –5 kPa [20,22]. Fig. 8 shows that the value of excess vapor pressure of motor fuel, taking into account its evaporation almost does not depend on the degree of filling the PP fuel tank, so further calculations used the values of the studied values for the case of filling the tank with liquid fuel by half, i.e. V_{fv} = 22.5 liters.

Also in Fig. 8 shows that the value of the excess vapor pressure of motor fuel in the tank in a certain temperature range does not exceed the value of p_{valve}. The temperature at which the values of p_{fv} and p_{valve} are equalized and the shut-off valve of the fuel tank is opened, t_{velve} is determined by formula (1.22) based on formulas (1.16)–(1.21) and is 35 °C (308 K) [26].

$$V_{fv}(T_0)=V_{fv}(T_{fv})\Rightarrow \Rightarrow \frac{m_{fv}(T_0)\cdot R\cdot T_0}{\mu_{fuel}\cdot p_{fv}(T_0)}=\frac{m_{fv}(T_{fv})\cdot R\cdot T_{fv}}{\mu_{fuel}\cdot p_{fv}(T_{fv})}\text{, m}^3, \quad (1.16)$$

$$m_{fv}(T_0)=(\mu_{fuel}\cdot V_{fv}\cdot p_{fvm}(T_0))/(R\cdot T_0)\text{, kg}, \quad (1.17)$$

$$m_{fv}(T_{fv})=(\mu_{fuel}\cdot V_{fv}\cdot p_{fvm}(T_{fv}))/(R\cdot T_0)\text{, kg}, \quad (1.18)$$

$$p_{fv}(T_0)=p_{fvm}(T_0)=p_0+p_{нп}(T_0)\text{, Pa}, \quad (1.19)$$

$$p_{fvm}(T_{fv})=p_0+p_{нп}(T_{fv})\text{, Pa}, \quad (1.20)$$

$$p_{fv}(T_{fv})=p_{fv}(T_0)\cdot\frac{m_{fv}(T_{fv})}{m_{fv}(T_0)}\cdot\frac{T_{fv}}{T_0}= =(p_0+p_{нп}(T_{fv}))\cdot\frac{T_{fv}}{T_0}\text{, Pa}, \quad (1.21)$$

$$p_{нп}(T_{fv})=\exp\left(\frac{(T_{fv}-273)-2{,}5}{53{,}439}\right)\cdot 10^3\text{, Pa}, \quad (1.22)$$

where μ_{fuel} = 172.3 g/mol; p_0 = 101325 Pa; T_{fv} = 273 K; R = 8.314 J/(mol·K); V_{fv} = 22.5·10^{-3} м^3; $p_{нп}(T_0)$ = 954 Pa; then $p_{fv}(T_0)$ = 102279 Pa; $m_{fv}(T_0)$ = 0,175 kg; $p_{нп}(T_{fv}$ = 313 K) = 2017 Pa; $p_{fv}(T_{fv}$ = 313 K) = 103342 Pa; $p_{нп}(T_{fv}$ = 323 K) = 2432 Pa; $p_{fv}(T_{fv}$ = 323 K) = = 103757 Pa.

Thus, after transformations and substitutions, and also provided that $p_{fv}(T_{fv}) = p_0 + p_{velve}$, and p_{valve} = = 15000 Pa, it was obtained the formula (1.23), using which the method of successive approximations obtained the dependence of the temperature t_{velve} on the pressure p_{valve}, presented in Fig. 9 and described by the least squares method by polynomial function – see formula (1.24) (R^2 = 1.0).

$$p_{valve}=(p_0+\exp((T_{fv}-275{,}5)/53{,}439)\cdot 10^3)\times \times T_{fv}/T_0-p_0\text{, Pa}, \quad (1.23)$$

$$t_{velve}=-7{,}0\cdot 10^{-3}\cdot p^2_{velve}+2{,}609\cdot p_{velve}-2{,}7\text{, °C}. \quad (1.24)$$

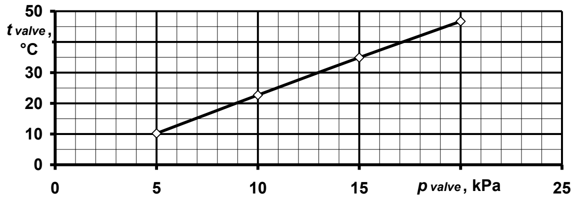

Fig. 9. Graph of dependency of the values of opening temperature of the shut-off valve of the fuel tank cover t_{velve} on the vapor pressure of the motor fuel p_{valve} to which the valve is set

It should also be noted that both formula (1.23) and formula (1.24) do not include the value of the volume V_{fv}, which explains the nature of the graphs in Fig. 8 and, in turn, is explained by the fact that in the equation of state of an ideal gas solved with respect to pressure, the mass of gas m_{fv} fully corresponds to its volume V_{fv}, and these values are in the numerator and denominator, respectively, and the gas is saturated vapor, that is, there is a thermodynamic similarity.

2 Results of assessment of the criterion with taking into account motor fuel vapor emissions and their analysis

Variants for calculated study

The study will consider the following variants of G(IB) emission values: Variant A – «Worst Global» – the valve is set to p_{valve} = 0 kPa, daily air temperature difference ΔT_{fv} is the maximum observed in populated areas of the Earth, i.e. in the desert ΔT_{fv} = 50 °C. Variant B – «Worst local» – the valve is set to p_{valve} = 0 kPa, the daily difference in air temperature ΔT_{fv} is the maximum observed in Kharkov ΔT_{fv} = 40 °C. Variant C – «Actual global» – the valve is set to p_{valve} = 15 kPa, the daily air temperature difference ΔT_{fv} is 50 °C. Variant B – «Actual local» – the valve is set to p_{valve} = 15 kPa, ΔT_{fv} = 40 °C.

Given that, in contrast to the value of the motor fuel vapor pressure in the fuel tank p_{fv}, which does not depend on the degree of filling the tank with motor fuel, but only on the temperature T_{fv}, the value of mass of vapors of motor fuel in the tank m_{fv} depends on the volume V_{fv} similarly to the value of emission G(IB).

In this study, it is assumed that the operation of the PP, equipped with the 2Ch10.5/12 diesel engine, with the already studied degrees of filling the fuel tank – 1/4, 2/4 and 3/4 – is equally likely, and therefore when obtaining the value of emission G(IB) uses the arithmetic mean of the mass m_{fv}. The value of the mass m_{fv} is obtained by the equation of state of an ideal gas as the difference for the initial and final state of a thermodynamic system. When obtaining the value of the duration of period of time between emissions, we will assume that the heating cycle of motor fuel in the tank is 1 day, i.e. τ_{IB} = 24 hours.

The results of the calculation study

Fig. 10 illustrates graphs of the dependence of the values of the mass of motor fuel vapor in the fuel tank m_{fv} on the degree of filling of the tank V_{fv} for different values of vapor temperature. Fig. 11 shows the value of the mass of volley emissions of motor fuel for one of its cycles $\Delta m_{fv\Sigma}$ for all variants of the calculation study. Fig. 12 illustrates the value of volley mass hourly emission of motor fuel vapors for one of its cycle G(IB) for all variants of the calculated study.

The calculation study considered the following variants for the composition of the set of ES factors, taken into account by the mathematical apparatus of the complex fuel-ecological criterion. Variant A – «Reference» – without taking into account the emission of motor fuel vapors coused by both LRB and SRB phenomena. Variant B – «Large» – with taking into account the emission of motor fuel vapors coused by LRB phenomena. Variant C – «Small» – with taking into account the emission of motor fuel vapors coused by SRB phenomena. Variant D – «Full» – with taking into account the emission of motor fuel vapors coused by both LRB and SRB phenomena.

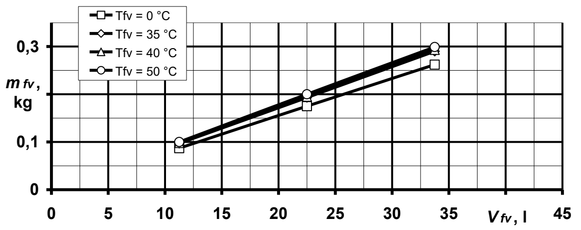

Fig. 10. Graphs of the dependence of the values of the mass of motor fuel vapor in the fuel tank m_{fv} on the degree of filling of the tank V_{fv} for different values of vapor temperature

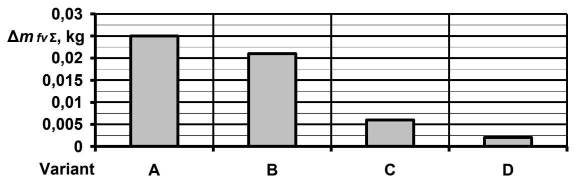

Fig. 11. Value of the mass of volley emissions of motor fuel for one of its cycles $\Delta m_{fv\Sigma}$ for all variants of the calculation study

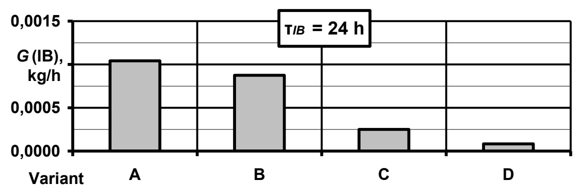

Fig. 12. Value of volley mass hourly emission of motor fuel vapors for one of its cycle G(IB) for all variants of the calculated study

Fig. 13 contains the distribution of the values of the mass hourly emission of motor fuel vapors coused by both LRB and SRB phenomena according to the regimes of the ESC testing cycle for 2Ch10.5/12 autotractor diesel engine. In Fig. 14 summarizes the distribution of the values of the K_{fe} criterion by regimes of the the ESC testing cycle for 2Ch10.5/12 autotractor diesel engine. In Fig. 15 shows the distribution of the values of the effect of δK_{fe} on the regimes of the ESC testing cycle for 2Ch10.5/12 autotractor diesel engine. Fig. 16 shows the distribution of the average operating values of the K_{fe} criterion and the effect of δK_{fe} for 2Ch10.5/12 autotractor diesel engine and all studied variants.

Fig. 13 shows that the individual regime values of the amount of motor fuel vapor emission from the tank is observed at the minimum idling regime (n_{cs} = 800 rpm, M = 0.6 N·m), and the maximum – at the nominal power regime (n_{cs} = 1800 rpm, M = 95 N·m). Fig. 14 and Fig. 15 show that taking into account the emission of motor fuel vapors caused by the SRB phenomenon have almost no effect on the individual regime values of the K_{fe} criterion according to the ESC cycle for the 2Ch10.5/12 diesel engine, but this effect is significant for the case of taking into account emission of motor fuel vapors caused by the LRB phenomenon.

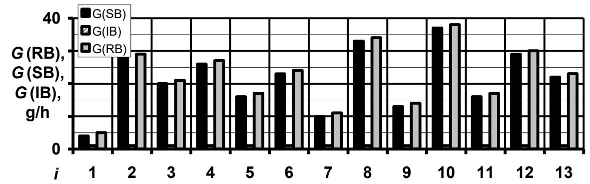

Fig. 13. Distribution of the values of the mass hourly emission of motor fuel vapors coused by both LRB and SRB phenomena according to the regimes of the ESC testing cycle for 2Ch10.5/12 diesel engine

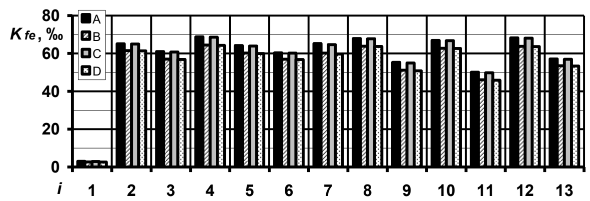

Fig. 14. Distribution of the values of the K_{fe} criterion by regimes of the the ESC testing cycle for 2Ch10.5/12 diesel engine

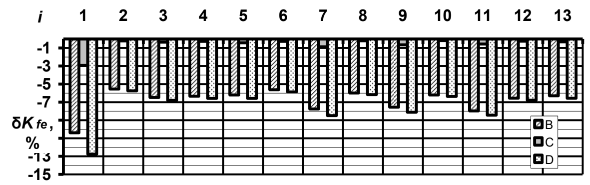

Fig. 15. Distribution of the values of the effect of δK_{fe} on the regimes of the ESC testing cycle for 2Ch10.5/12 diesel engine

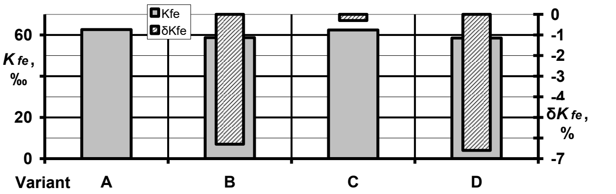

Fig. 16. Distribution of the average operating values of the K_{fe} criterion and the effect of δK_{fe} for 2Ch10.5/12 autotractor diesel engine and all studied variants

Fig. 16 shows that the average operational values of the K_{fe} crierion for the first variant differ to a lesser extent by the value of δK_{fe} up to 0.25 %, and for the second – up to 5.25 %.

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 the complex fuel-ecological criterion of Prof. I. Parsadanov with taking into account the mass hourly emissions of motor fuel vapor caused by the phenomena of large and small breathing of reservoirs. The essence of the proposed approach is to obtain the values of the ponderability of such a pollutant as the average of the field operating regimes of the diesel engine value of the ponderability of the fuel component of the complex fuel-ecological criterion A_{fuel} = 38.4; obtaining values of mass hourly emission of motor fuel vapor depending on the difference in daily air temperature, the degree of filling the tank with liquid fuel and the dynamics of its consumption by the engine and adjusting the spring of the two-way safety valve of the tank cap.

2. The set of initial data for the implementation of the calculation study for the ESC standardized steady testing cycle based on the analysis of the data of bench motor tests of 2Ch10.5/12 diesel engine. It was determined that the value of the mass hourly emission of motor fuel vapor caused by the SRB phenomenon under the assumptions does not depend on the settings of the safety valve of the tank cap, and the value of excess pressure in the tank does not depend on the degree of filling it by liquid fuel.

3. Calculated assessment of the values of the complex fuel-ecological criterion is carried out with taking into account the emissions of motor fuel vapors caused by the phenomena of LRB and SRB from fuel tank of the EU with RICE. It was determined that the individual regime value of the amount of motor fuel vapor emission from the tank is observed in the regime of minimal idling, and the maximum – in the regime of nominal power. It was also found that the average operational values of the K_{fe} criterion for the ESC cycle for 2Ch10.5/12diesel engine with taking into account the emission of motor fuel vapors caused by the SRB phenomenon has almost no effect (up to 0.25 %), but for the case of taking into account the effect of taking into account the emission of motor fuel vapors caused by the SRB phenomenon the impact is significant (up to 5.25 %). Identified dependences are described by formulas by the method of least squares.

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ВРАХУВАННЯ ВИКИДУ ПАРІВ МОТОРНОГО ПАЛИВА ПРИ КРИТЕРІАЛЬНОМУ ОЦІНЮВАННІ РІВНЯ ЕКОЛОГІЧНОЇ БЕЗПЕКИ ЕКСПЛУАТАЦІЇ ЕНЕРГОУСТАНОВОК З ПОРШНЕВИМ ДВЗ

О. М. Кондратенко , В. А. Андронов, Т. Р. Поліщук , Н. Д. Касьонкіна, В. А. Краснов

У цьому дослідженні запропоновано підхід для здійснення розрахункового оцінювання значень комплексного паливно-екологічного критерію проф. І.В. Парсаданова як показника рівня екологічної безпеки процесу експлуатації енергоустановок з дизельним двигуном з урахуванням масових годинних викидів пари моторного палива, спричинених явищами великого та малого дихання резервуарів. Метою дослідження є розробка способу для врахування параметрів викиду в навколишнє природне середовище такого полютанта, як парів моторного палива, зумовленого явищами великого та малого дихання паливних баків енергоустановки, як самостійного чинника екологічної безпеки при комплексному критеріальному оцінюванні рівня екологічної безпеки процесу експлуатації таких технічних об'єктів. Здійснено розрахункове оцінювання згідно до запропонованої методики з урахуванням властивостей моторного палива, ступеня заповнення паливного баку, особливостей моделі експлуатації двигуна, добового перепаду температури атмосферного повітря та налаштувань дихального клапана резервуара, та встановлено, що врахування викиду парів моторного палива, спричиненого явищем малого дихання, майже не чинить впливу на показники рівня екологічної безпеки, проте для варіанту врахування ефекту від явища великого дихання такий вплив є суттєвим. Наукова новизна отриманих результатів полягає у тому, що вперше запропоновано спосіб для врахування викиду парів моторного палива, спричиненого явищами великого та малого дихання паливних баків енергоустановок з поршневим двигуном внутрішнього згоряння при комплексному критеріальному оцінюванні показників рівня екологічної безпеки процесу їх експлуатації. Практична значимість отриманих результатів полягає у тому, що отримані результати придатні для надання кількісної і якісної оцінки досліджуваних ефектів та розробки на цій основі технічних рішень і організаційних заходів щодо їх зменшення чи зведення нанівець шляхом розробки відповідної технології захисту навколишнього середовища з виконавчими органами на методологічній основі системи управління екологічною безпекою, у тому числі й при застосуванні інших стаціонарних стандартизованих випробувальних циклів як моделей експлуатації двигунів.

Ключові слова: технології захисту навколишнього середовища; екологічна безпека; енергоустановки; двигуни внутрішнього згоряння; критеріальне оцінювання; викид парів палива; велике дихання резервуару; мале дихання резервуару.