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ENVIRONMETALLY FRENDLY STRUCTURE OF FIREFIGHTING AND EMERGENCY-RESCUE VEHICLE EXPLOITATION MODEL WITH RECIPROCATING ICE THAT OPERATES ON MIXTURE OF BIODIESEL AND PETROLEUM FUEL

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Ecological safety (ES) is a fundamental element of national security at both global and local levels. Its evaluation, particularly through complex criteria-based assessments, plays a key role in the final stage of the ecological safety management system (ESMS) within the framework of civil defence [1]. These considerations underscore the relevance of the present research [2]. The ES of firefighting and emergency rescue vehicles (FERV) has been the subject of numerous studies by both Ukrainian and international researchers, highlighting the growing relevance of criteria-based approaches to evaluating the ES level of such systems. This

relevance is further amplified by the pressuring need to address the fuel crisis driven by the depletion of fossil fuel reserves. A viable solution lies in the adoption of alternative fuels, with biodiesel being a primary candidate [1]. Developing advanced mathematical models for complex ES level assessments of FERVs with diesel reciprocating internal combustion engines (RICE) operation requires validated simulation data. This includes, in particular, models for pollutant formation and transformation in exhaust gas flows, using tools such as Blitz-PRO – an open-source ICE cycle simulation platform [3].

The study aligns with national strategic documents, including Presidential Decree № 722/2019 dated 30.09.2019 «About the Sustainable Development Goals of Ukraine for the period up to 2030» [4], and the «Regulation on the Organization of Environmental Support of the SES of Ukraine», approved by Order № 618 dated 20.09.2013 [5].

Purpose of the study. To develop a model for the accident-free operation of FERV equipped with RICE, and to optimize the structure of this model by considering the fuel and ecological efficiency of the operation process when using both conventional diesel fuel and blended fuels containing biodiesel. **Object of the study.** The accident-free operation process of FERVs powered by RICE. **Subject of the study.** The optimized structure of the operational model, with an emphasis on fuel and ecological efficiency when using both petroleum-based diesel and biodiesel-blended fuels.

Concept of the Exploitation Model

RICE-powered power plants (PP), including FERV and other specialized equipment operated by divisions of the SES of Ukraine, are significant sources of ecological hazard. These hazards determine the ES level of their accident-free operation [1,2].

To perform a complex assessment of the effectiveness of measures aimed at ensuring compliance with legislatively mandated ES levels – within the framework of the ESMS – it is recommended to apply the complex fuel and ecological criterion (K_{fe}) developed

by Prof. Ihor Parsadanov (NTU "KhPI") and further enhanced in [1]. Such an assessment requires the existence of an exploitation model tailored to the purpose and operational conditions of the RICE-powered systems. Currently, such model does not specifically exist for FERVs. The suggested exploitation model has been developed based on an averaged operational duty duration diagram of the State Fire and Rescue Departments (SFRD) of Kharkiv [2] (see Fig. 1) and includes six key operational segments (polygons): **1. Call Waiting** – the standby period in which the unit is on alert and awaiting deployment. **2. Call Forwarding** – the stage of dispatch and coordination, involving communication and routing to the incident. **3. Combat Deployment** – mobilization and travel to the emergency site under operational readiness. **4. Emergency and Rescue Operations** – active firefighting or rescue efforts utilizing engine-driven equipment. **5. Clotting of Equipment** – post-operation cooldown, deactivation, and securing of equipment. **6. Return to Location** – travel back to the base or station following mission completion.

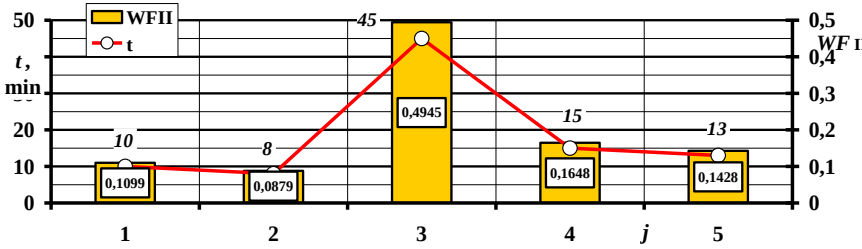

Figure 1. The developed exploitation model polygons parameters [2]

This research has been conducted within the framework of the scientific project "Development of a Methodology for Complex Assessment of the Environmental Impact of the Operation and Use of Special Equipment under Conditions of Military Aggression" (State Registration No. 0124U000374). The study utilized resources from the VCU library system, including electronic journals,

databases, and interlibrary loan services, accessed through participation in the Non-Resident Academic Associates Program, co-sponsored by the College of Humanities and Sciences at Virginia Commonwealth University and the Davis Center for Eurasian Studies at Harvard University during the 2024–2025 academic year.

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JUSTIFICATION OF RATIONAL UNITS OF MONETARY EQUIVALENTS OF ECOLOGICAL SAFETY LEVEL INDICATORS OF FIREFIGHTING AND EMERGENCY-RESCUE VEHICLES EXPLOITATION PROCESS

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Ecological safety (ES) is a critical component of national security on both global and local scales. Particular emphasis is placed on the economic aspects of the complex, criteria-based assessment of ES levels, which constitutes the final stage of the ES management system (ESMS) within the broader framework of civil defense system. These assessments serve as a foundation for management decisions in the field of civil defense service, relying on a specialized methodological framework [1]. The relevance of the study arises from this context. Moreover, the results may contribute to the development of methodologies for forecasting the operational costs and service life of firefighting and emergency rescue vehicles (FERV) equipped with reciprocating internal combustion engines (RICE) [2]. This is

particularly pertinent in scenarios where enhancing ES involves transitioning to the use of alternative, renewable motor fuels [3]. **Purpose of the study.** To provide a calculated grounding for the selection of rational units of measurement for the monetary components within the complex fuel-ecological criterion structure, used to assess the ES level of the exploitation process of power plants (PP) with RICE. **Object of the study.** The monetary components of ES level indicators related to the operation of PP powered by RICE. **Subject of the study.** The choice of appropriate units for expressing the monetary components and approaches for incorporating inflationary effects into their quantitative evaluation. The mathematical framework for the complex fuel-ecological criterion K_{fe} was originally developed by Prof. Ihor Parsadanov (NTU "KhPI") [4]. Current exchange rate data for major currencies relative to Ukrainian hryvnia are available on the official website of the National Bank of Ukraine [5]. The study aligns with national strategic documents, including Presidential Decree № 722/2019 dated 30.09.2019 «About the Sustainable Development Goals of Ukraine for the period up to 2030» [6], and the «Regulation on the Organization of Environmental Support of the SES of Ukraine», approved by Order № 618 dated 20.09.2013 [7].

Methodological Basis and Price Variants for Diesel Fuel

In the study, several historical variants of the price per kilogram of diesel fuel (P_f) have been calculated to justify the choice of appropriate monetary units for the K_{fe} criterion. These include: A) 1.81 ₴/kg – as recorded at the time of the publication of the monograph [4] (2003); B) 0.34 $/kg – USD equivalent of the Variant A; C) 23.08 ₴/kg – as recorded at the time of the publication of the monograph [2] (2018); D) 0.871 $/kg – USD equivalent of the Variant C; E) 29.40 ₴/kg – as recorded at the time of the publication of the monograph [1] (2019); G) 1.153 $/kg – USD equivalent of the Variant E.

The calculations have been performed using the D21A1 autotractor diesel engine (type designation 2Ch10.5/12 in accordance with ISO 3046-1:2002) as the reference model. Its technical specifications are provided in [1]. The exploitation model

applied was the 13-regime standardized steady test cycle, as defined by UNECE Regulation № 49 [1]. The initial dataset for this study has been derived from the analysis of bench motor tests, as described in studies [1-3], for the 2Ch10.5/12 autotractor diesel engine. This dataset includes the distribution of monetary components of the K_{fe} criterion across the engine's operational regime field.

To account for inflation in the chosen unit of expression for the value equivalents of the K_{fe} criterion, the study suggests using the mathematical framework of the Consumer Price Index (CPI). The CPI for the US dollar was 175 in 2003 and has since increased to 254 [1]. This inflationary adjustment is represented by formulas (1) and (2).

$$z_j = Z_j(t) \cdot CPI_{\$}(t)/100, \tag{1}$$

$$CPI = \sum\left(Q_i^t \cdot P_i^t\right) / \sum\left(Q_i^0 \cdot P_i^0\right) \cdot 100. \tag{2}$$

In the context of the study, index j denotes the type of monetary costs ($j = e$, f or fe), with t representing the current date. Z_j corresponds to the monetary costs in units of \$/(kW·h). Index i refers to the type of product, and index 0 represents the magnitude for the base period (for USD, the base period is 1982–1984, where the CPI = 100). The total quantity of produced goods is denoted by Q, and P represents the price of the produced goods in US dollars.

This research has been conducted within the framework of the scientific project «Development of a Methodology for Complex Assessment of the Environmental Impact of the Operation and Use of Special Equipment under Conditions of Military Aggression» (State Registration No. 0124U000374). The study has utilized resources from the VCU library system, including electronic journals, databases, and interlibrary loan services, accessed through participation in the Non-Resident Academic Associates Program, co-sponsored by the College of Humanities and Sciences at Virginia Commonwealth University and the Davis Center for Eurasian Studies at Harvard University during 2024–2025 academic year.

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