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### THE PLACE OF DPF WITH A LIQUID WORKING BODY IN THE CLASSIFICATION OF ATMOSPHERIC AIR PROTECTION TECHNOLOGIES FROM THE COMPLEX NEGATIVE INFLUENCE OF POWER PLANTS WITH RECIPROCATION ICE

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#### Abstract

In the article, which reflects the results of the authors' own research, the purpose of which was to improve the classification of methods and means of cleaning the exhaust gases flow of a reciprocating ICE from pollutants as environmental protection technologies by including in it executive devices for a complex effect on pollutants and factors of energy pollution of atmospheric air as a component the environment, in particular the DPF with a liquid working body, the following tasks were consistently solved regarding the improvement of the previously developed, listed in the open press and tested at a number of scientific and technical conferences of the design level of the executive device of the integrated action DPF and the improvement of the scientific product of information arrangement – a number of interconnected multi-level classifications – by determining the place of the device in these classifications, namely: analysis of literature data on environmental hazard factors, the source of which is a reciprocating ICE as part of a power plant; analysis of the classification of methods and means of reducing exhaust gases toxicity of diesel a reciprocating ICE; analysis of the classification of methods and means of cleaning exhaust gases of diesel a reciprocating ICE from PM; analysis of mechanical devices and systems for cleaning of exhaust gases of diesel a reciprocating ICE from PM; analysis of hydrodynamic methods of cleaning of exhaust gases of diesel a reciprocating ICE from PM and other factors of environmental danger; analysis of methods of regeneration of DPF with a liquid working body; analysis of the experimental recognition of the effectiveness of the use of DPF with a liquid working body; analysis of the neutralization of nitrogen oxides in the DPF with a liquid working body; analysis of the ozone method of neutralization of nitrogen oxides in exhaust gases of diesel a reciprocating ICE; analysis of the field of application of liquid neutralization of pollutants in the exhaust gases diesel a reciprocating ICE and improvement of the design of the diesel liquid neutralizer of exhaust gases diesel a reciprocating ICE. The object of the study is the classification of methods and means of cleaning the flow of exhaust gases of a reciprocating ICE from pollutants as environmental protection technologies. The subject of the study is the place of executive devices for complex impact on pollutants and factors of energy pollution of atmospheric air as a component of the environment, in particular, the DPF with a liquid working body, in the object of the study. The scientific novelty of the study results lies in the fact that the classification of methods and means of cleaning the exhaust gases flow of a reciprocating ICE from pollutants as environmental protection technologies by including in it executive devices for a complex effect on pollutants and factors of energy pollution of atmospheric air as a component the environment, in particular, DPF with a liquid working body. The practical significance of the study results is that the classification improved and supplemented in the study is useful for more detailed ordering of information and substantiation of the relevance of the development of individual complex innovative technologies of environmental management and the establishment of vertical and horizontal structural and logical relationships between the classification objects.

**Key words:** environmental protection technologies, ecological safety, power plants, reciprocating internal combustion engines, diesel particulate matter filter, classification, particulate matters, nitrogen oxides, unburned hydrocarbones, carbon monoxide, noise, heat pollution.

#### Statement of the problem and analysis of literary sources

Analyzing the current state of indicators of the level of ecological safety (ES) of the components of the environment, especially atmospheric air (AA), in the countries of the former USSR in general and in Ukraine in particular, it should be noted a tendency towards its deterioration in contrast to the countries of the European Union (EU) and the United States of America (USA), Japan and China. In these highly economically developed countries, there is a diametrically opposite situation, primarily due to strict environmental legislation and ensuring strict compliance with its requirements. Over the past more than 30 years, with an increase in the number of operating units of power plants (PP) with reciprocating internal combustion engines (RICEs) (especially diesel, taking into account the global trend towards dieselization) and motor vehicles (MV) and special equipment (SE) in particular, as well as a clearly ex-

pressed tendency to the constant deterioration of indicators of their technical condition due to moral and physical wear and tear (that is, age, period of exploitation, working hours in motor hours, etc.) and components of the natural environment (NE) is insufficient. Analyzing the rationality of the use of expensive and complex environmental protection technologies (EPT) – cleaning and recovery systems to increase the ES level indicators of the exploitation process of PP, MV, and SE, including emergency and rescue vehicles (ERV), which are on combat duty of units of the State Emergency Service of Ukraine (SES of Ukraine), primarily take into account the increase in the cost price of both themselves and products (in particular, mechanical and electrical energy) that are produced or transported with their help, and the costs of health protecting on the scale of the settlement, region and the whole country. Therefore, the creation of ES management systems (ESMS) of the exploitation process of PP, MV, and SE (in particular, ERV),

equipped with RICE (in particular, diesel) based on the executive devices of EPT – systems and units for cleaning or neutralizing pollutants in the flow of exhaust gases (EG) of RICE and subsequent neutralization of pollutants removed from the EG flow are promising and relevant from the point of view of energy and resource costs both on a national scale and on a global scale, as well as given the tasks set before the units of the SES of Ukraine under during war and during the period of post-war reconstruction of the country [1–3].

It is a well-known fact that, by definition, heat engines are sources of mechanical energy, i.e., they are heat engines that convert the heat supplied to the working body into mechanical energy [1, 2]. At the same time, heat engines with external heat supply – a steam engine, a steam turbine, and a Stirling engine – can use the following «inconvenient» types of primary heat energy sources: high-energy by-products of other technological processes (blast furnaces, mine gases, water vapor), renewable energy (solar energy), geothermal energy, steam from the cooling circuits of nuclear plants. In contrast to the above, internal combustion engines (ICE) – reciprocating, gasturbine, and rocket jet – create a primary source of thermal energy independently by releasing the energy of exothermic oxidation-reduction reactions of oxidation of liquid, solid, or gaseous fuels of petroleum or plant origin, inorganic compounds oxidizing agent – air oxygen, liquid oxygen, strong inorganic acids, saltpeter. Heat engines in the global dimension of energy-generating capacities occupy their own well-defined and rather wide niche, in particular, ICE occupy more than 80 % of the total power for mechanical and electrical energy in the energy balance of the highly economically developed countries of the world, which is produced by PP, and they are superior to engines with external heat supply in terms of the total amount and total produced energy [1, 2]. At the same time, it should be especially emphasized that for the conditions of the war and the post-war reconstruction of the country, for the needs of the units of the SES of Ukraine and utility companies with critical infrastructure, PP with diesel engines are irreplaceable as sources of mechanical energy (land, water and rail transport, small aviation, mobile motor-compressors, motor pumps, mixers of concrete, ERV and SE, military equipment, construction, and agricultural, mining and warehouse equipment, etc.), electric energy (as part of diesel generators for household and unbreakable points, mobile electric welding stations) and thermal energy (PP with heat recovery and free-piston gas generators) in remote, hard-to-reach areas affected, not subjected to humanitarian demining, unequipped and unelectrified due to damage and destruction of infrastructure facilities, as well as in reserve energy supply in case of an emergency [1–3].

In the last four decades, there has been a clear trend towards dieselization of the PP fleet with RICE in transport – an increase in the share of RICE that work according to the Rudolph Diesel cycle (engines that consume heavy motor fuels, with qualitative power regulation and self-ignition from compression, with the internal fuel-and-air mixture formation, i.e. diesel engines or diesel), in the entire batch of such PP, which is due to a wide range of influencing factors. Among the

number of such factors, according to the vast majority of experts in the industry, one of the most important is the fact that other things being equal, diesel pollutes environment to a lesser extent [1–23]. At the same time, fuel consumption during the operation of diesel RICE is approximately 25 % lower than that of RICE that operate according to the Nikolaus Otto cycle (gasoline-consuming engines with quantitative power regulation and external fuel-and-air mixture formation, with spark ignition). In addition, diesel RICE have more than twice the technical resources, are much better structurally adapted to power increasing when using gas turbine supercharging, have higher fire and explosion safety indicators, allow to obtain more power in one unit, etc. [1]. On the other hand, there is an existing extension of certain principles of operation of diesel RICE to the organization of work processes in other types of RICE – an increase in the value of the compression ratio, the transition to a two-stroke cycle, and the use of supercharging, distributed and direct fuel injection, the creation of layering of a fresh charge of local zones in the combustion chamber with a value of the coefficient of excess air  $\alpha$  significantly different from the stoichiometric one, etc.

At the moment, well-known specialists in RICE, when creating their new samples, solve the main tasks listed in [1, 2] (a visual distribution of these tasks is presented in Fig. 1):

- 1) improvement of the fuel efficiency indicators of RICE;
- 2) improvement of the reliability indicators of RICE;
- 3) improvement of the ecological indicators of RICE;
- 4) improving indicators of the cost of production, exploitation, maintenance, and repair of RICE;
- 5) specific: multi-fuel consumption; forcing and deforcing; conversion. Provision of specific, predetermined, weight-size indicators, indicators of fire and explosion safety, ensuring unification with other types of road transport etc. should also be included as specific [1, 2].

All of the above-mentioned tasks are solved interrelatively, but for different types of RICE, some of them have a higher priority than the rest. So, for example, for RICE of aviation, military, and SE, ERV, the most priority task is to ensure the highest possible reliability, in particular, fail-safe operation, which is critical in the conditions of flight, combat operations, and liquidation of emergencies. However, the requirements for the level of ES indicators of the exploitation of the PP with RICE are of particular importance against the background of the rest, because they are fixed at the legislative level [1–23], that is, they are mandatory, even though the requirements for the results of solving the rest of the defined main tasks of engine construction are formed exclusively by the economical laws of free competition [1, 2].

In the EU countries, UNECE Regulations R-49 of EURO VI level are currently in force for MV with RICE, and for Ukraine – EURO V level standards have been formally implemented [2]. However, it should be noted that all measures to ensure that the technical level of the diesel RICE meets the next level of these standards increase its cost by 40 % [1, 2]. Particulate matter

(PM) as the main pollutant in the composition of EG of diesel RICE accounts for 20–45 % of their total equivalent toxicity because they contain carcinogenic and mutagenic substances [1, 2].

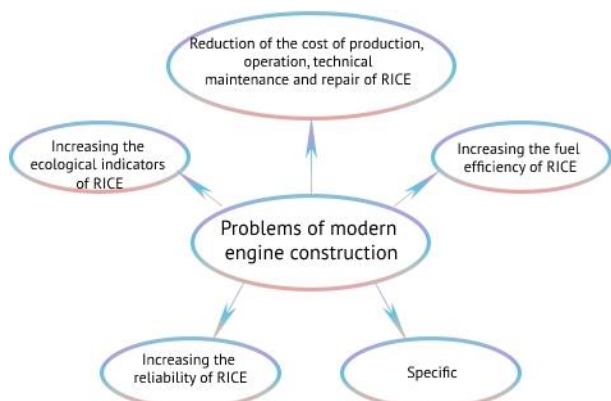


Figure 1 – The main tasks of modern engine designing (construction) and production industry [1, 2]

On the other hand, a significant contribution to the pollution of environment components by the emission of pollutants with the EG flow of diesel RICE is also explained by the significant number of facilities in the structure of the MV fleet of our country that are equipped with diesel RICE that have been in exploitation for more than a decade and a half and were not equipped with at the beginning of exploitation devices for reducing the toxicity of their EG, or got rid of them during exploitation due to various circumstances [1, 2]. The dieselization of the world's MV fleet and the significant spread of EG recirculation systems in their design, which require mandatory purification of the EG flow [1, 2], together determine the need to equip them with executive devices of EPT as a material base of the ESMS. This problem becomes especially urgent for MV operating in conditions of limited air exchange and in crowded places, in resort and nature reserve areas, these are shunting diesel locomotives, warehouses, quarry, construction and mining machines, vessels working in water areas of resort towns and military and SE, including ERV [1–3].

Thus, increasing the level of ecological performance indicators of diesel RICE, in particular diesel, in all highly economically developed countries of the world is an urgent and permanent task of the transport engineering industry and the sub-industry of engine production, and maintaining their values at the legislative established level is an actual and permanent task of the field of operation of PP with RICE. The results of solving these problems are highlighted in the works of leading scientists from Ukraine and the CIS countries, namely: Abramchuk F.I., Bashyrov R.M., Brazovskiy V.V., Varshavskiy I.L., Vasiliev I.P., Grekhov L.V., Gutarevich Y.F., Zvonov V.A., Kanilo P.M., Kudryash A.P., Kulchitskiy A.R., Levterov A.M., Mateychyk V.P., Marchenko A.P., Markov V.A., Novoselov A.L., Parsadanov I.V., Polivya'nchuk A.P., Shapko V.F., Smiles V.I., Shokotov N.K., Stokov O.P. etc.; as well as specialists of foreign companies and organizations, namely: AVL,

Bosch, Ricardo, Johnson Matthew, Engelhart, DCL, Emitech, Boshart, Rhodia, Volvo, MAN, Toyota, SAE, EPA, CARB, WHO, Massachusetts Institute of Technology, Society for Mining, Metallurgy and Exploration, Chalmers University of Technology, University of Minnesota, West Virginia University, Mining and Mineral Sciences Laboratories, Kobe University, Massachusetts Department of Environmental Protection, Idaho National Laboratory, Colorado Air Pollution Control Division, Virginia Polytechnic Institute, California Environmental Protection Agency, University of Cincinnati, University of Auckland, University of Tennessee, etc., among which the work of the following personalities should be highlighted: Eastwood P., Bugarsky A.D., Bari S., Strom H., Bickel K., Karin P., Hanamura K., Kettleson D.B., Boothe B.J., Majewsky W.A., Campbell M.G., Twigg M.V., Johnson T.V., Muter J.P. and others, whose works were subjected to a thorough analysis in the source [1,2].

Among the scientists who carried out their research in the field of ES and EPT of transport, alternative energy carriers, hybrid and electric vehicles, protection of atmospheric air from the dispersed phase of aerosols of various origins, monitoring of the condition of environment components and the construction of the ESMS, the works of should also be noted of Avramenko A.M., Andronov V.A., Atamas A.I., Bgantsev V.N., Borysenko V.G., Vambol S.A., Vambol V.V., Vnukova N.V., Gurets L.L., Danchenko Y.M., Dyachenko V.G., Yeroshchenkov S.A., Zipunnikov M.M., Klyuchka Yu.P., Koziy I.S., Kozulia T.V., Kozula M.M., Kostenko K.V., Koloborodov V.G., Korogodsky V.A., Kryvtsova V.I., Krot O.P., Levterova L.I., Malyovanov M.S., Marynin V.S., Marakhovskiy V.P., Plyatsuk L.D., Ponomarenko R.V., Solovey V.V., Umerenkova K.R., Yurchenko V.A., Shmandiy V.M. and others, whose works are also carefully analyzed in [1, 2].

The development of DPF with a liquid working body can become the material basis of the EPT from the complex (physico-chemical) impact of PP with diesel RICE [3–5], especially when using alternative types of motor fuels of biological origin [6–9,18,19]. When disposing of waste from the burning of hard coal and masure at thermal power plants [10] and other types of combustible production waste [11], disposing of livestock waste [12] and gas emissions from oil storage tanks [14], it is also necessary to develop effective executive devices of EPT for purification of aerosol gas emissions in AA with a liquid working body, taking into account their metrological characteristics [13]. About the implementation of a complex criteria-based assessment of the efficiency of the use of such executive devices, one should take into account as many factors as possible of the EHF [15–17, 20–23].

The development of DPF structures and their FE [1, 2, 4, 5, 38–40, 42–50, 55–57] is currently being carried out based on the results scientific studies on modeling and experimental research of their work processes and the process of their regeneration [25–29, 31–33, 35–37, 41, 43, 51, 53, 54, 58–60], their coordinated work with other executive devices of the corresponding EPT in the on-board pollutant neutralization system in the flow of EG of diesel RICE,

which is also the exhaust tract [24, 30, 34, 52], which additionally indicates the high relevance of research in the specified knowledge area.

Considering the above, it can be confidently stated that the chosen topic of research, the results of which are presented in the article, is relevant both on a global and local scale, especially considering the prospects of solving the problems of the post-war recovery of the economic of our country and the participation of personnel in it and SE of the units of the SES of Ukraine, in particular, in the development of effective, technological and easy-to-maintain and operate executive devices of EPT for complex influence on pollutants and factors of energy pollution of AA as a component of the environment of PP with RICE with different degrees of moral and of physical wear with a low cost, rational weight and size parameters, suitable for setting up serial production at domestic enterprises and building a standard-size series for RICE of various types and capacities, in particular DPF with a liquid working body.

**The purpose of the study.** Improvement of the classification of methods and means of purification the EG flow of a RICE from pollutants as EPT by including in it executive devices for a complex influence on pollutants and factors of energy pollution of AA as a component of the environment, in particular, an DPF with a liquid working body. **The problem of the study** is to provide a basis for improving the classification of methods and means of purification the EG flow of RICE from pollutants as EPT in the development of executive devices for complex influence on pollutants and factors of energy pollution of AA as a component of the NE.

**The object of the study.** Classification of methods and means of purification the EG flow of RICE from pollutants as EPT. **The subject of the study.** The place of executive devices for complex purification on pollutants and factors of energy pollution of AA as a component of the environment, in particular, DPF with a liquid working body, in the object of study.

**The tasks of the study** are as follows.

1. Analysis of literary data on the factors of ecological hazard, the source of which is RICE as part of the PP.

2. Analysis of the classification of methods and means of reducing the toxicity of EG of diesel RICE.

3. Analysis of the classification of methods and means of purification of EG flow of diesel RICE from PM.

4. Analysis of mechanical devices and systems for purification of EG flow of diesel RICE from PM.

5. Analysis of chemical devices and systems for purification of diesel EG flow of diesel RICE from PM.

6. Analysis of hydrodynamic methods of purification EG flow of diesel RICE from PM and other factors of environmental hazard.

7. Analysis of methods of regeneration of DPF with a liquid working body.

8. Analysis of the experimental determination of the efficiency of the use of DPF with a liquid working body.

9. Analysis of the neutralization of nitrogen oxides in DPF with a liquid working body.

10. Analysis of the ozone method of neutralization

of nitrogen oxides in EG flow of diesel RICE.

11. Analysis of the field of application of liquid neutralization of pollutants in the composition of EG flow of diesel RICE.

12. Improvement of the design of the diesel liquid neutralizer of EG flow of diesel RICE.

During the implementation of this study, the following **research methods** were used: analysis of scientific and technical, reference, normative, and patent literature, methods of organizing information, and building hierarchical classifiers.

Analysis of the results of the performed study allows us to highlight the following aspects of their **scientific novelty**. The classification of methods and means of cleaning the EG flow of RICE from pollutants as EPT *have gained further development* by including in executive devices for a complex influence on pollutants and factors of energy pollution of AA as a component of the environment, in particular, DPF with a liquid working body.

The results of the performed study can acquire the following **practical value**. The classification improved and supplemented in the study *is useful* for a more detailed arrangement of information and justification of the relevance of the development of separate complex innovative EPT and establishing vertical and horizontal structural and logical relationships between the objects of the classification.

### 1 Analysis of literary data on the factors of ecological danger, the source of which is the PDVZ as part of the EU

In the study [1, 2], a classification of ecological hazard factors (EHF) was developed, the source of which is the RICE as part of the PP in two approximations. However, there was an urgent need to expand, clarify, and supplement this classification, to present it comprehensively for the stage of «exploitation» of the life cycle of such technical objects. Based on this classification, in its third approximation, a classifier based on the hierarchical principle was built, it is displayed in the Table 1 and described in [2].

In the study will be showed the place of executive devices of EPT of complex impact on the improved classification, namely DPF with liquid working body.

In this classifier:

– positions A.a.1.1, A.a.1.2, B.c (highlighted in **green** color) – EHF taken into account by the original mathematical apparatus of the complex fuel-ecological criterion of Prof. Igor Parsadanov  $K_{fe}$ ;

– positions A.a.2.1–A.a.2.3, A.a.3.1–A.a.3.3, B.a.1, B.a.2 (highlighted in **gray** color) – EHF that appear in the process of accident-free exploitation of the RICE and can be taken into account by the improved mathematical apparatus of the  $K_{fe}$  criterion;

– positions A.b.1.1, A.b.1.2, A.b.2.1, A.b.2.2, A.b.3.1, A.b.3.2, B.a.3, B.b.1–B.b.3, C.a–C.c (highlighted in **orange** color) – factors that do not manifest themselves in the process of accident-free exploitation of RICE and cannot be taken into account by the original and improved mathematical apparatus of the  $K_{fe}$  criterion, to take them into account should be developed another criteria-based mathematical apparatus.

Table 1 – Hierarchical classifier of EHF, the source of which is RICE as part of the PP [2]

Classification code	FACTOR OF ECOLOGICAL HAZARD	Current status
<b>A</b>	<b>POLLUTANTS</b>	2 out of 14
<b>A.a</b>	<b>Gaseous and aerosol substances-pollutants</b>	2 out of 8
<b>A.a.1</b>	<i>Legislative regulated directly</i>	2 of 2
<b>A.a.1.1</b>	Emission of products of incomplete combustion of motor fuel in the flow of EG aerosol (C <sub>n</sub> H <sub>m</sub> , CO, PM)	Yes
<b>A.a.1.2</b>	Emission of products of complete combustion of motor fuel, in the flow of EG aerosol (NO <sub>x</sub> )	Yes
<b>A.a.2</b>	<i>Legislative regulated indirectly</i>	0 out of 3
<b>A.a.2.1</b>	Emission of sulfur oxides in the EG aerosol flow (SO <sub>x</sub> )	No
<b>A.a.2.2</b>	Emission of surfactants and heavy metal compounds in the flow of EG aerosol (benz(a)pyrene, PAH, TES)	No
<b>A.a.2.3</b>	Emission of greenhouse gases in the EG aerosol flow (CO <sub>2</sub> , H <sub>2</sub> O, CH <sub>4</sub> , NO <sub>x</sub> )	No
<b>A.a.3</b>	<i>Legislative not regulated</i>	0 out of 3
<b>A.a.3.1</b>	Emission of motor fuel and oil vapors caused by large and small reservoir breathing phenomena	No
<b>A.a.3.2</b>	Emission of an aerosol of crankcase gases	No
<b>A.a.3.3</b>	Increase in humidity of atmospheric air (H <sub>2</sub> O)	No
<b>A.b</b>	<b>Liquid pollutants</b>	0 out of 6
<b>A.b.1</b>	<i>Flammable and explosive</i>	0 out of 2
<b>A.b.1.1</b>	Pollution of NE with motor fuel	No
<b>A.b.1.2</b>	Pollution of NE with motor oil	No
<b>A.b.2</b>	<i>Non-flammable</i>	0 out of 2
<b>A.b.2.1</b>	Pollution of NE with coolant	No
<b>A.b.2.2</b>	Pollution of NE with brake fluid	No
<b>A.b.3</b>	<i>Consistent</i>	0 out of 2
<b>A.b.3.1</b>	Pollution of NE with consistent lubricants	No
<b>A.b.3.2</b>	Pollution of NE with preservation liquids	No
<b>B</b>	<b>HARMFUL INFLUENCE FACTORS</b>	1 out of 6
<b>B.a</b>	<b>Energy pollution of NPS</b>	0 out of 3
<b>B.a.1</b>	Pollution of NE by noise and vibration	No
<b>B.a.2</b>	Pollution of NE by heat	No
<b>B.a.3</b>	Pollution of NE by electromagnetic fields	No
<b>B.b</b>	<b>Information pollution of NPS</b>	0 out of 3
<b>B.b.1</b>	Pollution of NE with false information	No
<b>B.b.2</b>	Pollution of NE with informational noise	No
<b>B.b.3</b>	Pollution of NE by disturbing factors	No
<b>B.c</b>	<b>Consumption of a non-renewable source of energy</b>	yes, 1 out of 1
<b>C</b>	<b>WASTE (SOLID POLLUTANTS)</b>	0 out of 3
<b>C.a</b>	Pollution of NE with alloys of ferrous and non-ferrous metals	No
<b>C.b</b>	Pollution of NE with polymer and composite materials	No
<b>C.c</b>	Pollution of NE with glass and ceramic substances	No

**2 Analysis of the classification of methods and means of reducing the toxicity of EG of diesel RICE from PM**

In world practice, there are several methods of reducing the emission of PM in the flow of EG of RICE. The features of the fractional and chemical composition of EG of diesels RICE in general do not allow us to be satisfied with one of them [1–23]. In the study proposed the following classification of the reduction of the

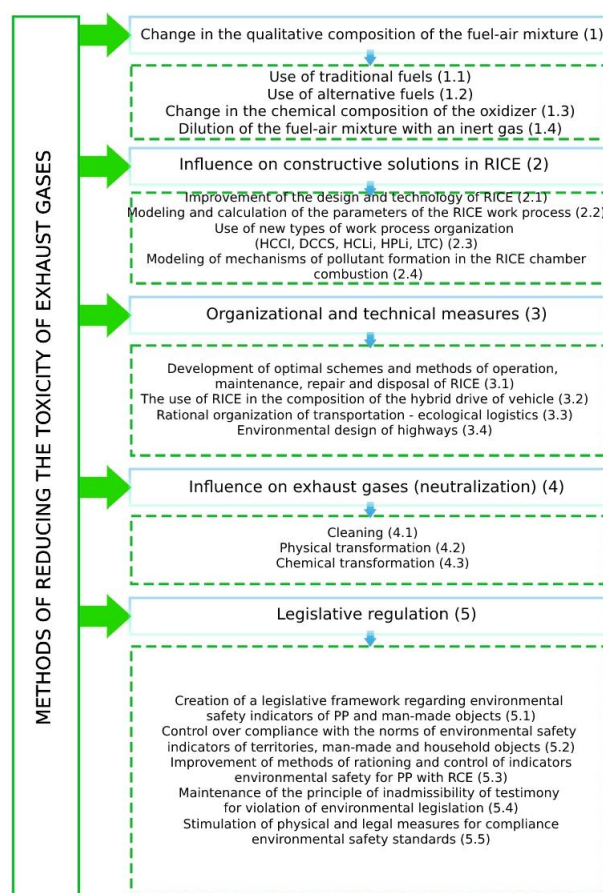


Figure 2 – Classification of methods of reducing the toxicity of EG of RICE [1,2]

emission of PM in the EG flow, if the type of RICE for a certain PP is finally chosen as diesel (see Fig. 2), which is also described and illustrated in detail in [1, 2].

1. Change in the qualitative composition of the fuel-and-air mixture, which can be achieved by the following measures:

- 1.1. when using traditional fuels:
  - 1.1.1. improving the quality of traditional fuels of petroleum origin,
  - 1.1.2. improving the quality of motor oils,
  - 1.1.3. constant controlling of their quality indicators;
- 1.2. when using alternative fuels:
  - 1.2.1. using 100 % alternative fuels of biological origin;
  - 1.2.2. using mixed fuels,
  - 1.2.3. transition to a gas-diesel work process,
  - 1.2.4. increasing the hydrogen number of fuel by adding hydrogen to the water-and-air mixture;
- 1.3. when changing the chemical composition of the oxidizer:
  - 1.3.1. enriching the fuel-and-air mixture with oxygen,
  - 1.3.2. transferring RICE to operation on pure oxygen,
  - 1.3.3. adding ozone to the fuel-and-air mixture,
  - 1.3.4. ionization of air at the intake;
- 1.4. when diluting the fuel-air mixture with an inert gas:

- 1.4.1. by injecting water vapor into the combustion chamber,
- 1.4.2. using EG recirculation;
- 1.4.3. by transferring RICE to a closed cycle of operation.
- 2. Influence on the constructive decisions of the RICE:
  - 2.1. improvement of construction and technology of production of RICE;
  - 2.2. modeling and calculation of the parameters of the working process of the RICE;
  - 2.3. use of new types of working process organization (HCCI, DCCS, HCLi, HPLi, LTC);
  - 2.4. modeling of pollutant formation mechanisms in the RICE combustion chamber
- 3. Organizational and technical measures:
  - 3.1. development of optimal schemes and methods of operation, technical maintenance, repair and disposal of the RICE;
  - 3.2. application of RICE as part of the hybrid drive of MV;
  - 3.3. rational organization of transportation – ecological logistics;
  - 3.4. environmental design of highways.
- 4. Influence on EG – neutralization in various ways using various systems and devices through their:
  - 4.1. purification (filtering);
  - 4.2. physical transformation;
  - 4.3. chemical transformation.
- 5. Legislative regulation:
  - 5.1. creation of a legislative framework regarding indicators of the level of ES of PP and man-made objects;
  - 5.2. control over compliance with the norms of indicators of the ES level of territories and technogenic and household objects;
  - 5.3. improvement of methods of norming and controlling of indicators of the ES level for PP with RICE;
  - 5.4. maintenance of the principle of inevitability of punishment for violation of ecological legislation;
  - 5.5. stimulation of individuals and legal entities to comply with the ES norms, including the creation of social advertising on relevant topics, encouragement of PP with RICE owners by providing various benefits, targeted reduction of the tax burden loading etc.

The improvement of motor fuels in the light of increasing the ecological indicators of diesel RICE mainly consists in limiting the content of sulfur in them (preferably its complete exclusion from the composition of fuel and motor oils) and surfactants. Also, the measures that reduce the toxicity of EG of diesel RICE include the addition of various anti-smoke additives that interfere with the formation of PM in the working process of diesel RICE, and additives that reduce the combustion temperature of PM in the fuel tank during its regeneration.

The use of alternative fuels for diesel RICE, including hydrogen, has gained limited application due to the unpreparedness of resource-production bases and in-

frastructure to provide transport with the required amount of fuel of the appropriate quality. At this time, the use of the gas-diesel working process became more widespread. Of all the measures to change the chemical composition of the oxidizer, only EG recirculation is used in practice.

The methods of reducing PM emission in terms of improving the construction of RICE include the following:

- 2.1.1. optimization of the shape of the combustion chamber;
- 2.1.2. the use of fuel supply equipment that ensures a high level of injection pressure (and, therefore, the required degree of atomization and long-range fuel torch), dosing accuracy, the necessary injection law (for a diesel RICE, it is either systems with pump-injectors, or systems of the Common Rail type);
- 2.1.3. use of electronic control and regulation (including with adaptation and emergency protection algorithms);
- 2.1.4. use of supercharged air parameter management (adjustable turbocharger, supercharged air cooling, means of intensification of the vortex movement of the air charge in the cylinder);
- 2.1.5. use of cooling and cleaning of EG during their recirculation;
- 2.1.6. control of gas distribution phases, compression ratio, number of working cylinders, order of cylinders working and diesel stroking;
- 2.1.7. optimization of such transient processes as start-up (including cold), acceleration, braking (including by the engine), stopping the diesel RICE.

### 3 Analysis of the classification of methods and means of purification of EG of diesel RICE from PM

It has been established that according to the design features of cleaning systems and devices, EG from PM are traditionally classified (see Fig. 3) [1, 2]:

- A) according to the principle of action (A):
  - A.1. the wall-flow type – closed type systems;
  - A.2. the separation type – open type systems;
- B) according to the degree of purification:
  - B.1. full current;
  - B.2. partially current;
- C) for material of the filter element (FE) [1, 2].

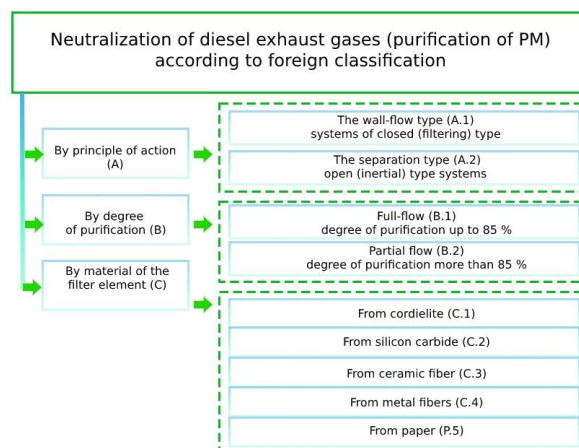


Figure 3 – Foreign classification of DPF designs [1, 2]

DPF characterized by cleaning efficiency in the range of 50–85 % are called partial flow, their main advantage is low hydraulic resistance (HR) (backpressure) and a long inter-regeneration period of operation. Such DPF are widely used during modernization MV. DPF with a degree of purification of the EG flow from PM, greater than 85 %, are called fully current [1, 2]. The material of their FE of DPF is divided as follows:

C1. From cordielite. They are distinguished by almost the greatest efficiency of cleaning EG, a relatively low price, as well as a low tendency to thermal shock destruction, thanks to which it is possible to make a monolithic FE from them, but a relatively low boiling temperature (1200 °C), which significantly increases their tendency to melt during prolonged or uncontrolled involuntary (passive) thermal regeneration and overflowing by PM.

C2. From silicon carbide. They are distinguished by a significantly higher melting temperature (2700 °C) but are more expensive than cordielite, with which they are interchangeable with the same overall dimensions. However, they are thermally unstable, which necessitates the manufacture of large and medium-sized FE from separate segments that are fastened with special thermo-elastic cement. They retain up to 95 % of PM with sizes of 0.2–150 μm.

C3. From ceramic fiber. They usually consist of several types of ceramic fibers, mixed (entwined) in such a way as to obtain an optimal combination of GR and effective porosity of the gas-permeable walls of FE of arbitrary shape. They create a smaller GR than the previous types of FE materials, with the highest efficiency of purification of EG (in the range of PM sizes less than 100 nm up to 95 % by mass and up to 99 % by number) in a wide range of diesel RICE operating regimes.

C4. From metal fibers. The FE of such DPF consists of layers of woven or non-woven metal (steel) meshes. The main advantage of such a FE is the possibility of heating it by passing an electric current through it, which contributes to the creation of conditions necessary for the regeneration of DPF at low temperatures or low EG flow rates at the filter inlet. However, FE made of these materials are significantly more expensive than ceramic ones, and are not interchangeable with them, since they are conductors.

C5. From paper. These are disposable flow filters, which are used in those cases when the MV, which is not equipped with an DPF with the required degree of EG purification, is used for a short time in explosion- and fire-hazardous and trade-storage premises. Regeneration of such DPF is not foreseen, they require preliminary cooling of the EG.

The above classification at this stage of the development of scientific and technical thought and for solving the tasks set in the study is not enough for generalization and systematization of information about the principles of operation of systems and devices for purification EG flow from PM. This is because several physical and chemical methods of EG flow treatment are used in diesel EG neutralization devices and systems, in particular, purification from PM, as revealed by the research (see Fig. 4) [1, 2].

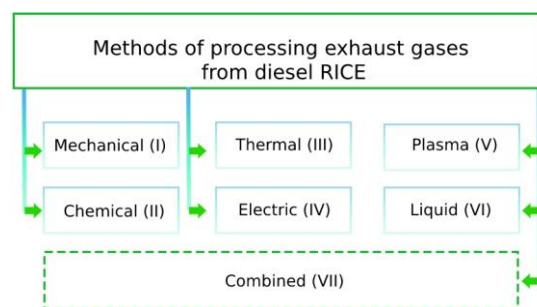


Figure 4 – Classification of physical-chemical methods of processing waste gases to neutralize PM in them [1, 2]

In accordance with the above-mentioned methods, which are the basis of the operation of such systems and devices, the study proposes a multi-level classification, built using the principles of decimal division, fundamentally described in [1, 2]. The study presents an extended, improved and illustrated version of the proposed classification. According to the principle of operation, devices and systems for purification EG flow from PM are divided into types (see Fig. 5 [1, 2]).

1. Mechanical type. Change the vector of the velocity of movement of PM relative to the streamline of the flow of the aerosol «EG–PM» both in direction and in magnitude (preferably – reduce to zero). Built on mechanical, electrical, liquid methods of processing EG.

2. Chemical (oxidizing) type. Convert combustible components of PM into non-toxic or less toxic pollutants using redox reactions. Built on chemical, thermal, plasma and liquid methods of processing EG.

3. Combined type. Combine two or more of the above methods of processing EG.

Types of devices and systems are divided into subtypes.

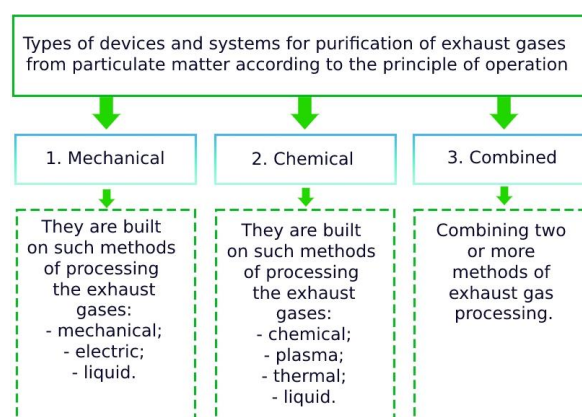


Figure 5 – Classification of devices and systems for purification EG flow from PM by type [1, 2]

#### 4 Analysis of mechanical devices and systems for purification of EG of diesel RICE from PM

Mechanical devices and systems built on mechanical methods of processing EG can be divided into the following subtypes according to the principle of operation [1, 2]:

1.1. filtering, or those that use a filtering method that retains PM when they are in direct contact with the FE material using the phenomena of adsorption and/or adhesion. In foreign terminology, this is “the wall-flow

type”, or closed type systems;

1.2. inertial ones, or those that use an inertial method, which changes the direction of specially prepared PM aggregates and separates them from the EG flow with the help of inertial forces. In foreign terminology, this is “the separation type”, or open type systems.

Devices that use a filtering method (according to the classification subtype 1.1), according to the correspondence of the sizes of the holes in the FE material matrix and the sizes of the PM to be filtered (that is, according to the structure of the FE), can be divided into types:

1.1.1. solid microporous with holes that do not exceed the size of PM, or filtering. Such FE absorb and retain relatively large fractions of PM mainly by the outer surfaces of the FE channels with gas-conducting walls and additionally by the space in the holes in the FE material;

1.1.2. solid macroporous with holes exceeding the size of PM. Relatively small fractions of PM are absorbed and retained by the space in the holes in the FE material when the shapes of the current lines of the EG flow change when it passes through the porous FE material;

1.1.3. with continuous medium (liquid). PM and gaseous harmful fractions of EG are absorbed when their flow passes through the layer of the working fluid;

1.1.4. solid wetted (solid porous or with winding). PM and gaseous harmful fractions of EG are absorbed when their flow washes the tops of solid FE elements with a thin layer of working fluid (or gel-like substance) applied to them;

1.1.5. solid sprayed (solid non-porous or with winding). PM and gaseous harmful fractions of EG are absorbed when their flow washes the surfaces of solid FE elements with a thin layer of sprayed (glued) solid porous substance applied to them.

According to the material structure of the FE matrix, the types of devices and systems for cleaning EG 1.1.1 and 1.1.2 can be divided into the following form factors [1,2]:

- 1.1.1.1. or 1.1.2.1. monolithic ceramic;
- 1.1.1.2 or 1.1.2.2. monolithic metal-ceramic;
- 1.1.1.3 or 1.1.2.3. wound, or FE with winding;
- 1.1.1.4 or 1.1.2.4. bulk, or FE with bulk;
- 1.1.1.5 or 1.1.2.5. combinations of any of the above.

Monolithic ceramic FE (according to the classification of form factors 1.1.1.1 and 1.1.2.1) are made by:

- sintering,
- deposition,
- foaming methods.

According to their configuration, monolithic ceramic FE can belong to:

- 1.1.1.1.1 or 1.1.2.1.1. continuous porous solid body,
- 1.1.1.1.2 or 1.1.2.1.2. of a solid body with a cellular (cellular) structure.

In FE from a continuous porous solid body, the process of cleaning the EG flow takes place when it passes through the entire body of the filter, which can have the following geometric shapes [1,2]:

- a prism,
- a cylinder,
- a ring,

– a cone.

FE made of a solid body with a cellular structure have channels with gas-permeable walls, which are blocked at the ends in a checkerboard pattern. One of them, blocked on the side of the EG flow exit from the FE, is intended for the entry of the untreated EG flow into the FE. The others, silenced on the side of the EG flow entrance to the FE, are intended for the output of the purified EG flow from the FE. Purification of the EG flow from PM occurs when it passes through the gas-permeable walls of the channels [1, 2].

According to the geometric configuration of the direction of the channels, such FE can be:

- longitudinal (the FE itself has the shape of a prism or a cylinder),
- radial (the FE itself has the shape of a cone or a ring) [1, 2].

Channels can have the geometric shapes of:

- a prism,
- a cylinder,
- a pyramid,
- a cone.

Their walls can be distributed evenly or unevenly in the FE cross-section [1, 2]. According to the area of the lumbar cross-section, the channels can be the same or not the same (for example, the input channels are larger than the output channels) [1, 2]. The area of the filtering surface of such FE is usually 1 m<sup>2</sup> per 1 dm<sup>3</sup> of the FE volume, while the wall thickness is 0.3...0.5 mm, and the density of channels in the FE is 15...50 channels per 1 cm<sup>2</sup> of the FE cross-section [1, 2].

Monolithic metal-ceramic FE (according to the classification of form-factors 1.1.1.2 and 1.1.2.2) are made by powder metallurgy methods. They can consist of the following:

1.1.1.1.1 or 1.1.2.1.1. a single piece of porous material;

1.1.1.1.2 or 1.1.2.1.2. individual blocks with geometric shapes, as in FE.

Wound FE (according to the classification of form factors 1.1.1.3 and 1.1.2.3) have a regular or chaotic winding or tangle of:

- fibrous materials,
- threads,
- wire,
- metal microgrids (woven or non-woven),
- their combinations.

According to their configuration, wound FE can look like this:

1.1.1.3.1 or 1.1.2.3.1. windings on frames [1, 2], where the frame can have the form of a drum made of wire (or narrow steel strips) or a perforated steel sheet. According to the type of material, the winding can be:

- wire,
- fibrous,
- tangled,
- mesh;

according to the type of material:

- steel,
- ceramic fiber,
- carbon fiber;

according to the number of layers:

- single-layer,



– multi-layer;

by direction:

– unidirectional,

– crossed;

1.1.1.3.2 or 1.1.2.3.2. a flat package consisting of layers of corrugated and/or perforated steel sheet, which directs and redistributes the flow of EG, and layers of sheet woven or non-woven material or mesh. Sheets or a net, which limit the package, differ from the parts inside the package by greater strength [1, 2];

1.1.1.3.3 or 1.1.2.3.3. a package rolled up in a spiral (spiral package) according to the structure of the layers is similar to a flat package 1.1.1.3.2 or 1.1.2.3.2 [1, 2];

1.1.1.3.4 or 1.1.2.3.4. a set of packages rolled into truncated cones of various sizes, which are assembled coaxially and muffled (package-cone) by the design of layers is similar to flat package 1.1.1.3.2 or 1.1.2.3.2 [1,2].

Bulk FE (according to the classification, form factors 1.1.1.4 and 1.1.2.4) have the form of a set of special elements – cartridges or cassettes, consisting of a case with gas-permeable walls and an embankment [1, 2].

Bulk is a powder (a loose dry substance) with pronounced sorption properties of a certain fractionation by the size of the granules. Depending on the degree of binding, the bulk in the cassette can be:

– free, compressed,

– briquette,

– bound with special substances.

Filler granules can be:

– granulated (artificially obtained),

– rolled,

– crushed according to the manufacturing method.

According to the origin of the material, the embankment can be made of:

– natural,

– artificial materials,

according to the type of materials [1, 2]:

– from zeolites of various types and origins

– thermally expanded graphite,

according to the number of materials used:

– mono-embankment,

– composite embankment.

Bulk FE can consist of:

a) single container;

b) mono-container divided into compartments by inseparably connected membranes;

c) several separate containers (cassettes) separately connected.

According to the material, the cassettes are divided into:

– porous ceramic,

– perforated metal sheets,

– grids.

According to the geometric shape, the body of bulk FE is divided into:

– cylindrical,

– box,

– conical.

Solid-state large-pore FE with holes exceeding the dimensions of PM (according to the classification of device type 1.1.2) are used only together with inertial or electrical methods, as well as with means that organize

the flow of EG especially or use self-organization of the flow of EG in long and ornate channels from connected pores or holes (cells) of windings and nets.

Depending on the properties of the FE material, they can be divided into the following classes by the place of PM retention:

1.1.1.a. surface-retaining (adsorption);

1.1.2.b. volume absorbing (absorbing).

Surface-retaining (adsorptive) devices are those that absorb and retain small fractions of PM with their upper layer and structurally correspond to solid-state microporous FE with holes that do not exceed the size of PM (type of devices 1.1.1). The following FE should be included among them:

1.1.1.a.1. with spraying of various ceramic materials of a certain thickness, strength, and porosity on the walls of non-porous material [1, 2];

1.1.1.a.2. with wet-type winding or winding (watered with liquids to increase adhesive qualities, which in a thin liquid film is equivalent to the phenomenon of adsorption). Volumetric absorbing (absorbing) – absorb and retain PM in their entire volume.

According to the aggregate state of the body, FE can be:

– monolithic porous (1.1.2.b.1);

– liquid (1.1.2.b.2) [1, 2].

Inertial methods (according to the classification, subtype devices 1.2) change the direction of movement of specially prepared PM aggregates. According to the method of changing the PM motion vector, inertial methods should be divided into:

1.2.1. gas-dynamic, which changes the vector of the speed of movement of PM by influencing the hydrodynamic parameters of the entire EG flow;

1.2.2. electromagnetic, which changes the vector of the speed of movement of PM that has an electric charge, through the influence of an electromagnetic field on the flow of EG.

According to the method of formation of particles with sufficient mass, all inertial methods can be of the following types [1, 2]:

a) 1.2.1.1 or 1.2.2.1 droppers;

b) 1.2.1.2 or 1.2.2.2 coagulating;

c) 1.2.1.3 or 1.2.2.3 condensing.

FE built using droplet inertial methods form aggregates of PM and droplets sprayed in the flow of EG liquids – water or engine oil [1, 2]. FE built on the use of coagulation inertial methods form aggregates only with PM due to the introduction of special additives into the composition of fuel or EG [1, 2]. FE built on the use of condensing inertial methods form aggregates of PM and liquid droplets that are formed from the products of fuel combustion (water and unburned hydrocarbons) that condense during their forced cooling [1, 2].

In mechanical devices and systems with FE, built on the use of electrical methods, the change in the vector of motion of PM relative to the current line of the EG flow occurs due to the presence of an electrostatic charge in PM and the induction of a weak electromagnetic field in the material of FE. Therefore, to ensure their operation, their FE are made of conductive materials. It also contributes to the formation of PM aggregates by droplet, coagulation, or condensing methods [1, 2].

FE that use electrical methods directly to clean EG from PM should also include those in which metal grids with needles, to which a constant electric voltage is applied, catalyze redox reactions between PM and oxygen in EG [1, 2].

**5 Analysis of chemical devices and systems for purification of EG of diesel RICE from PM**

In devices that use chemical (or oxidizing) methods (according to the classification, device type 2 is chemical), combustible components of PM are transformed into non-toxic or less toxic pollutants using redox reactions [1, 2]. According to the principle of operation, they are divided into the following subtypes:

- 2.1. catalytic;
- 2.2. thermal;
- 2.3. plasma;
- 2.4. oxide or post-catalytic.

Catalysts are used in systems for purification EG from PM with FE, the principle of operation of which is based on the use of catalytic methods (according to the classification of device subtype 2.1), substances that change the speed and/or conditions of the oxidation-reduction process reactions. At the same time, FE catalytic devices can be divided into the following types according to the location of the catalyst [1, 2]:

2.1.1. with the application of the catalyst on the surface of the FE in the form of spraying or a gel-like substance;

- 2.1.2. with fuel injection;
- 2.1.3. with submission directly to EG.

Systems for cleaning EG from PM, built on the use of thermal methods of their processing (according to the classification of device subtype 2.2), ensure the necessary temperature of EG, at which the combustible components of PM are spontaneously oxidized by residual oxygen in EG. At the same time, such FE can be divided according to the type of heat source as follows [1, 2]:

- 2.2.1. fuel that is additionally supplied to the diesel RICE combustion chamber or directly to the EG;
- 2.2.2. electric heating elements that are structurally part of the body or housing of the FE (incandescence coils), or are separate units (glow plugs);
- 2.2.3. an external source located outside the MV.

Systems for purification EG from PM with FE, the principle of operation of which is based on the use of plasma methods (according to the classification of device subtype 2.3), use low-temperature plasma generated by special devices to oxidize PM in the flow of EG plasmons or use the plasma of an electric arc (spark discharge) between FE electrodes formed from a metal grid. According to the plasma generation time, there are:

- 2.3.1. spark-discharge methods, that is, continuous on a microscale and intermittent on a macroscale of time;
- 2.3.2. methods with long-term (continuous on a macrotime scale) plasma guidance. At the same time, according to the type of substance – the plasma carrier, these FE can be divided into the following types [1, 2]:
  - 2.3.1.1 or 2.3.2.1. with the use of EG;
  - 2.3.1.2 or 2.3.2.2. with the use of air that is separately supplied to the EG.

Systems for purification EG from PM with FE, the principle of operation of which is based on the use of oxide methods (according to the classification of devices subtype 2.4), use nitrogen dioxide NO<sub>2</sub>, which is obtained for the oxidation of PM in the flow of EG excessively in the catalytic after-oxidizer of products of incomplete combustion of fuel, installed above the DPF on the EG flow in the exhaust system of the diesel RICE [1, 2].

In devices that use a liquid method of cleaning EG, soluble components of EG are removed by dissolving them in the working fluid of the FE, if they are wetted by it. Insoluble and non-wettable components of EG (including PM) are removed from the flow of EG by absorbing them with the working fluid of the neutralizer, provided that a solid layer is previously created on the surface of PM and its retention due to the surface tension of the liquid – so-called liquid filters [1, 2].

The efficiency of cleaning EG of diesel RICE from PM for DPF, which is used in their work is depicted in Fig. 6 [1, 2].

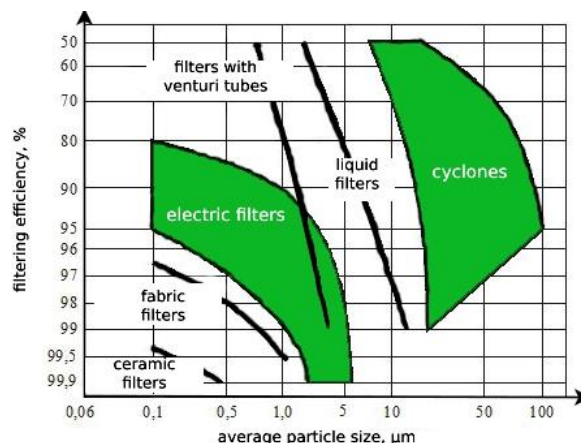


Figure 6 – Efficiency of EG purification of diesel RICE from PM by filters with different operating principles [1, 2]

In practice, only combined methods are used (device type 3 – combined), taking into account the fact that PM contains various substances both in terms of their chemical and physical properties. Due to the preciousness of PM, they are not replaced after clogging, but regenerated, that is, PM, accumulated by filtration, is removed from the filter itself by thermal or other methods.

In addition to DPF for purification EG of diesel RICE fuel from products of incomplete combustion of fuel oxidizing catalytic or thermal neutralizers are used, in which PM is partially oxidized, but it is difficult to completely oxidize them there, so this method is used only in combination with PM.

EG cleaning devices of stationary powerful diesel RICE – scrubbers with water jets or Venturi tubes and liquid filters designed to reduce emissions of incomplete fuel combustion products and PM – can be classified as mechanical devices with FE, which are built on the use of droplet inertial methods (according to the classification, type 1.2.1.1 or 1.2.2.1 – droplet FE) [1, 2].

Most often, an DPF with a ceramic porous FE is used, on the surface of which a catalyst is applied for

partial post-oxidation of incomplete combustion products, reduction of the regeneration temperature of the DPF and catalytic NO<sub>x</sub> absorber, etc.

Thus, this part of the study describes the improved classification of methods and means of cleaning the

flow of EG of diesel RICE from PM, which is fundamentally different from the existing ones both in terms of the number of classification features and the nomenclature of classified objects. Generalized information is presented in Fig. 7 [1, 2].

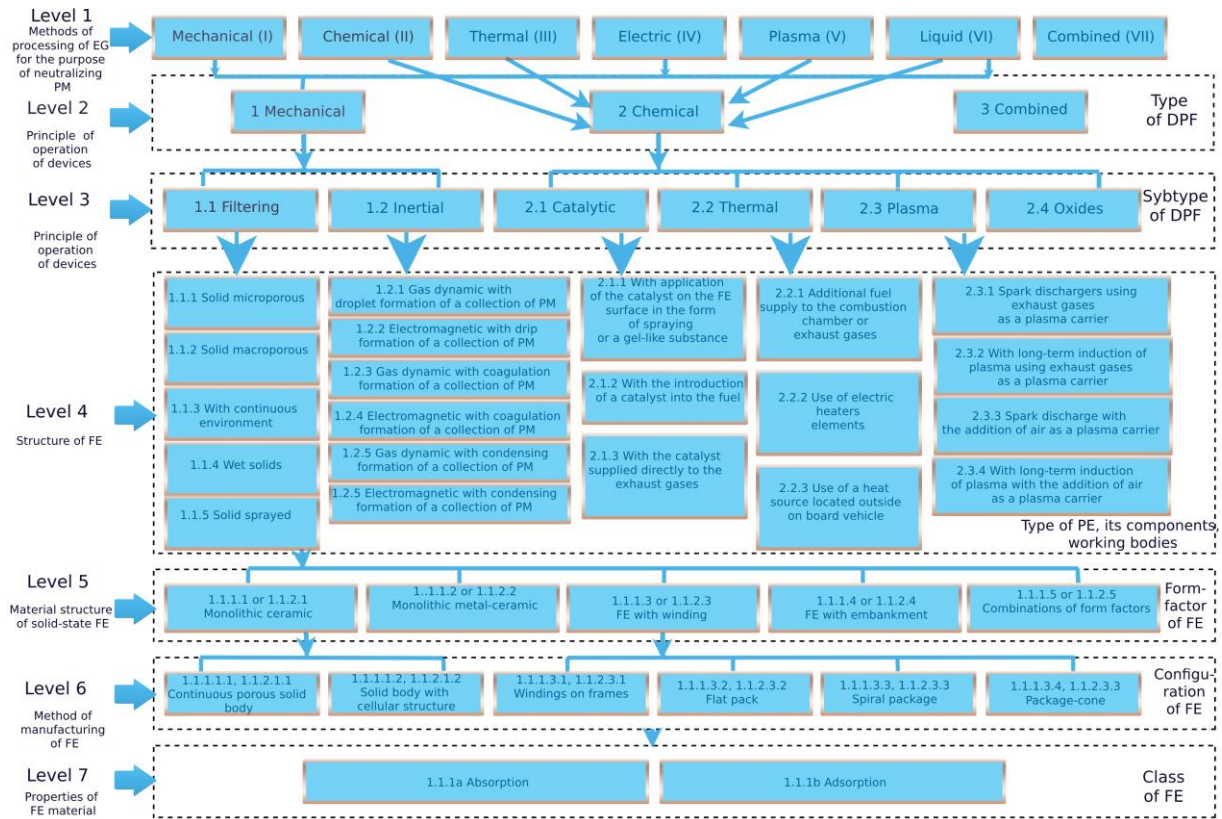


Figure 7 – Classification of systems of complex purification of aerosol of EG of diesel RICE from PM [1, 2]

### 6. Analysis of hydrodynamic methods of purification of EG of diesel RICE from PM and other ecological hazard factors

Reducing the emissions of harmful substances from the EG of RICE is an important direction to reduce the pollution of AA as a component of the NE. EG neutralization systems make it possible to significantly reduce the amount of pollutant emissions with the EG flow of diesel RICE.

The following physicochemical methods of EG treatment are most often used to effectively reduce the quantitative indicators of pollutant emissions with the EG flow of diesel RICE [3–5]: catalytic, thermal, and liquid neutralization of EG. A significant drawback of the catalytic method of EG neutralization is that during operation, resinous deposits and PM accumulate on the surface of the catalyst, as well as sulfur compounds from motor fuel and motor oil is «poison» for the catalytic coating, which leads to the fact that the efficiency of EG purification is sharply reduced. The disadvantages of thermal neutralization are as follows: some decrease in power and an increase in mass hourly specific effective fuel consumption due to the increase in HR of the RICE exhaust system.

Compared to the methods described above, the method of liquid neutralization of EG is the simplest and most economical method of physical-chemical influence on EG of diesel PP.

The main advantages of liquid neutralization of pollutants in the EG flow of diesel RICE in a broader formulation of the problem are [1–5]:

- the possibility of simultaneous capture of dispersed PM and neutralization of toxic gaseous and water-soluble components of EG;
- cooling of EG to a temperature of 40–80 °C, which is important when working in explosive environments;
- effective spark extinguishing, which ensures fire and explosion safety;
- ensuring the neutralization of pollutants in the EG flow at the initial moment after the start of the cold RICE;
- decrease in the intensity of the smell of EG;
- reduction of the noise level of EG emissions of diesel RICE;
- the possibility of further use of the soluble components of EG and dispersed PM extracted from WL during its regeneration.

The main disadvantages of liquid neutralization of EG of diesel RICE in a broader formulation of the problem [3–5]:

- the problem of wetting of very fine PM (with a size in the micron range);
- relatively low efficiency of neutralization of gaseous components of EG;
- relatively large mass and dimensions;
- removal of WL steam by the EG flow in the AA;

– the need for periodic replacement and disposal of WL, which complicates and makes operation more expensive;

– corrosion problems;

– freezing of WL at low temperatures.

Theoretical and experimental research, initially carried out by the author's team from the Department of Hydrogen Energy (formerly – the Department of Piston Power Plants) of the A.M. Pidgorny Institute for Mechanical Engineering Problems of National Academy of Sciences of Ukraine and continued in co-authorship with scientific and pedagogical workers and students of the third (educational and scientific) level of higher education under the Educational and Scientific Program of higher education “Technogenetic and Ecological Safety” in the Specialty 183 “Environmental Protection Technologies” in the Field of Knowledge 18 “Production and Technologies” of the Department of Applied Mechanics and Environmental Protection Technologies (formerly – the Department of Applied Mechanics) of the Faculty of Technogenic and Ecological Safety of the National University of Civil Defence of Ukraine of State Emergency Service of Ukraine, the research was aimed at developing an economical and effective system for liquid neutralization of pollutants in EG of diesel RICE with a nominal power up to 200 hp (147 kW), which can be used for autonomous stationary diesel PP, for example, diesel generators, as well as RICE test stations and individual boxes. Modification of the system for transport of diesel RICE can be installed on tractors, truck loaders, special (including mining and quarrying, warehouse) equipment, and on MV, primarily on ERV and SE of units of the SES of Ukraine [3–5].

The principle of operation of the developed system of liquid neutralization of pollutants in the EG flow of diesel RICE is based on the principles of inertial liquid purification. As is known, the efficiency of the inertial method is determined by the mass characteristics of the PM extracted from the EG flow. The main PM are soot nuclei together with the unburnt hydrocarbons of motor fuel and motor oil adsorbed by them. When the temperature of the EG decreases, coagulation of PM occurs. The speed of PM coagulation is determined by the concentration and size of PM, the degree of their polydispersity, shape, and presence of adsorbed films, as well as the turbulence of the EG flow and the degree of their temperature reduction. In general, the cleaning of dispersed PM is based on the violation of their aggregative and kinetic stability and their removal from the EG flow by the force of the inertial field [3–5].

Using effective hydro-gas-dynamic purification processes, a liquid inertial neutralizer was developed as an executive device of EPT, which implements the proposed method of purification of EG from pollutants, provides adsorption, condensation, capture of fine PM and filtration of EG. The neutralizer consists of two stages, which are made in the form of metal containers partially filled with WL – fresh technical water. In the first, there is a collector with working nozzles that form a EG flow. The EG flow, moving in jets from vertically located nozzles, hits the surface of the WL, and then is directed to the second stage through special channels. Here, the EG flow is fed into the annular gas distributor

and, passing through the nozzles located on its side surface, bubbles in the WL column. Next, the EG flow through the moisture separator, which prevents the removal of WL drops from the device, is thrown into the AA. The stages are also connected by an overflow device, which is designed to return from the second stage to the first WL carried out by the EG flow [3–5].

The HR of such a liquid pollutant neutralizer in the EG of a diesel RICE is less than the standard PP EG muffler with the RICE, which allows neutralization of the EG without additional power withdrawal of the RICE, and therefore it is supposed to be installed instead of a standard muffler [3–5].

On the experimental bench with a D21A1 (according to GOST 4363–482Ch10.5/12) diesel engine, studies of the operation of the liquid inertial neutralizer of pollutants in the EG of a diesel RICE were carried out, which showed that several factors affect the efficiency of purification EG from PM.

The velocity of the EG flow from the nozzles, starting from some minimum value (about 30 m/s), practically does not affect the efficiency of purification the EG of diesel RICE from PM. At the same time, the rational value of the EG flow rate is determined by the value of the smallest HR of the liquid neutralizer and the guaranteed velocity margin about the minimum value. The recommended velocity of outflow from the nozzles is 50...60 m/s, provided by the selection of the diameter and number of nozzles. A rational knowledge of the distance from the nozzle cut to the free surface of the WL is 0.025...0.030 m, which is determined by the range of the EG jet and the minimum value of the HR. With a long distance from the nozzle cut to the WL in certain operating modes of the RICE, the range of the EG jet may not be sufficient to ensure the required degree of purification of the EG from PM. Approaching the nozzles to the surface of the liquid or immersion in it leads to an increase in the value of HR [3–5].

The temperature of the EG significantly affects the efficiency of the liquid neutralizer. 130...150°C should be recognized as a rational value of the EG temperature. A higher EG temperature leads to the heating of the entire structure, at the same time WL heats up, WL vaporization and removal of WL in the AA increase, and as a result, the degree of EG purification from PM decreases. It is impractical to lower the temperature of the EG in front of the neutralizer below 130 °C since the conditions for precipitation and accumulation of PM on the walls of the connecting pipeline of the neutralizer appear. The increased temperature of WL also affects the level of purification of EG. When heating WL, starting from a certain temperature (140°C), the degree of purification of EG decreases. The amount of WL with the maintenance of a rational temperature value has little effect on the degree of purification of EG from PM [3–5].

Studies of the influence of such factors as the area of the free surface of the WF, the location of the nozzles, and the height of the liquid column showed that they have a weak effect on the efficiency of the liquid neutralizer – the degree of purification of the EG flow of the diesel RICE from PM, and are not the main ones in the design of the inertial liquid EG neutralizer [3–5].

Thus, the obtained results make it possible to determine the rational values of the factors that determine the course and efficiency of the processes of hydrodynamic purification of EG from PM and to create an effective, economical system of liquid inertial neutralization of EG of diesel RICE of various PP, primarily ERV and SE of divisions of the SES of Ukraine.

### **7. Analysis of methods of regeneration of DPF with a liquid working body**

When using liquid neutralization of pollutants in the EG flow of diesel RICE, it is necessary to solve the problem of WL disposal. Possible options for organizing this process are as follows: centralized at special treatment plants; directly in the location of the neutralization and mixed systems. Moreover, each of them determines the choice of the method of cleaning WL, as well as the financial and material costs for their implementation. The first option includes the collection and transportation of WL, processing it, and disposal of components obtained as a result of cleaning WL. The second is cleaning of WL at the place of work, collection and transportation of components obtained as a result of cleaning components, and their disposal. With the first method, it is possible to provide an effective and economical technology for cleaning WL (when processing sufficiently large volumes of WL, for example, when equipping a powerful test stand for a diesel RICE or a powerful stationary diesel generator with a stationary liquid neutralization system). However, taking into account that in most cases with liquid neutralization of EG, technical fresh or offshore seawater is used as WL, it is economically impractical to return it after cleaning from dissolved and absorbed pollutants from a specialized station for reuse. With the second option, there are no costs for transportation of WL, the reuse of purified WL is ensured, but at the same time, autonomous systems for complete chemical cleaning of spent WL are required [3–5].

Thus, it is rational, both from an economic and technical point of view, to use a mixed version of spent WL cleaning, in which at the place of operation of EG neutralization systems from pollutants, WL cleaning from absorbed PM and its reuse is carried out. Then, after completing several cycles of recycled WL, when the concentration of dissolved pollutants in WL (aldehydes, sulfur oxides, the highest nitrogen oxides, etc.) reaches a certain critical level, the spent WL is drained and transported to special stations for complete purification and utilization of purified water and disposal of products cleaning.

The research on the regeneration of DPF with a liquid working body, the results of which were presented in this article, was aimed at creating an effective and economical technology for cleaning WL from the pollutants removed from the EG flow and accumulated in it, which ensures the possibility of its reuse. Based on the PM precipitation method, two methods of cleaning WL from PM were developed. The WL cleaning system consists of a sedimentation tank, which includes two special tanks, draining and WL pumping systems.

The first method is intended for quick (within 2 hours) cleaning of WL from PM. Cleaning is carried out

with the help of a chemical reagent – electrogenerated aluminum coagulant  $Al(OH)_3$ . To clean WL, pour it into one of the sedimentation tanks and add an aluminum-based coagulant to it. At the same time, the second container is a backup. After two hours, the coagulant, together with PM particles, completely settles to the bottom of the first tank and is relatively easily separated from the purified WL (technical freshwater), which can be reused in the pollutant neutralization system in EG. The rational content of aluminum-containing coagulant was determined experimentally:  $0.1 \text{ m}^3$  of coagulant with a concentration of  $0.05 \text{ kg/m}^3 \text{ Al}^{(3+)}$  per  $1 \text{ m}^3$  of treated WL [3–5].

The second method allows you to clean WL from PM without using chemical reagents. However, this process takes more time.

It is known [1, 2] that the composition of PM in diesel RICE includes (by mass): soot – 25 %, sulfates – 10 %, hydrocarbons of unburned motor fuel – 15 %, hydrocarbons of unburned motor oil – 50 %. Taking into account the value of the density of each of the listed components, it can be established that the average density of PM is  $1140 \text{ kg/m}^3$ , which is significantly higher than the density of water. Experimental studies have shown that the efficiency of precipitation of PM significantly depends on the temperature of the cleaned WL. When the temperature of the WL is higher than the ambient temperature, convective jets are formed in the liquid, which captures PM and prevents their precipitation. When the WL temperature decreases, convective jets weaken and completely disappear at normal ambient temperature.

Based on these studies, the authors of the article developed a technology for cleaning WL, in which it is poured into one of the tanks of settling tanks, where it settles, cooling down to ambient temperature, at this temperature it is kept for 3–5 hours for more complete precipitation of PM. Then the settled WL from the upper part of the container is pumped into the EG neutralizer, and the sediment together with the WL remaining in the settling tank is removed for further processing. The presence of two sedimentation tanks allows you to alternately pour untreated WL into one of them, and from the second receive cleaned WL and return it to the EG neutralizer. Thus, the operation of the neutralizer depends to a lesser extent on the duration of the WL cleaning cycle [3–5].

### **8. Analysis of the results of the experimental determination of the effectiveness of the use of the DPF with a liquid working body**

One of the ways to reduce AA pollution in industrial zones is to reduce the emission of pollutants with the EG flow of stationary PP with diesel RICE and during bench tests of the diesel RICE themselves. With minimal material and time costs, this can be achieved by using stationary pollutant neutralization systems in the EG flow. The development and improvement of such systems help to solve the problems of ensuring the legislative established level of the values of the corresponding technogenic and ecological safety indicators.

Centralized stationary systems for purifying the EG flow from pollutants are mainly used at test stations of

diesel RICE. The peculiarity of such a system for the Science Technical Center was the need to equip each test box with an autonomous local stationary unit for neutralizing pollutants in the EG flow, which has a minimum HR [3–5].

The autonomous unit for the neutralization of pollutants in the EG flow developed by the authors of the study for the test boxes of the Science Technical Center consisted of two stages, which were made in the form of metal tanks partially filled with WL – technical fresh water. In the first stage, with a volume of 1.7 m<sup>3</sup>, there is a collector with working nozzles with a diameter of 26 mm, which forms a flow of purified EG. Moving in the form of jets from vertically located nozzles, the EG hits the free surface of the WL, and then through special channels they are sent to the second stage, the volume of which is 0.9 m<sup>3</sup>. Here, EG is fed into the annular gas distributor and, passing through the nozzles located on its side surface, bubbles into the WL column. Further, EG through a moisture separator, which prevents the removal of WL droplets, is thrown into the AA [3–5].

To perform experimental studies, the developed pollutant neutralization unit in EG as an executive element of EPT was manufactured at the STC and mounted on the technical floor above the test station box of the Engine Plant. The first stage was filled with technical fresh water with a volume of 0.65 m<sup>3</sup>. An aqueous solution of KMnO<sub>4</sub>(1 %) + HNO<sub>3</sub>(0.4 %) was poured into the second stage, the volume of which was 0.28 m<sup>3</sup> [3–5].

Measurements of the operating parameters of the diesel RICE were carried out using the standard devices of the test bench. Opacity parameters of the EG flow were measured by the Bosch model 703 device, and the NO<sub>x</sub> concentration in the EG flow was measured by the Thermo Electron 44 series device.

The tests were performed at three speed regimes of the KamAZ-740 diesel engine (loading characteristics): at  $n_1 = 2600 \text{ min}^{-1}$ ; at  $n_2 = 1800 \text{ min}^{-1}$ ; at  $n_3 = 1200 \text{ min}^{-1}$ . The main test results are shown in Table 2 [3–5].

The analysis of the obtained data shows that the developed EG neutralization system is operational in the entire range of operating regimes of the diesel RICE and provides a low level of HR. The degree of NO<sub>x</sub> neutralization could be determined only on one regime, because the tightness was broken due to the strong oxidizing properties of the chemical solution. The temperature of EG decreased from 170...225°C to 62°C, which allows to ensure fire safety requirements [3–5].

The results of the field tests mainly confirmed the data in [1, 2] obtained earlier by theoretical assessment and preliminary experiments and showed the need to refine the system to increase the efficiency of neutralization of EG of diesel PP.

### 9. Analysis of the neutralization of nitrogen oxides in DPF with a liquid working body

RICE, in particular diesel, is one of the main sources of pollution of AA. In places of concentration of MV or SE with diesel RICE, in particular, ERV of divisions of the SES of Ukraine, especially in specific conditions – in limited spaces (quarries, mines, test stations,

Table 2 – Test results of bench tests at the Engine Plant of the stationary liquid system for neutralization of pollutants in the EG flow for KamAZ-740 type diesel RICE [3–5]

Parameters	Crankshaft rotation frequency, min <sup>-1</sup>		
	$n_1 = 2600$	$n_2 = 1800$	$n_3 = 1200$
Effective power $N_e$ , kW	151.2	113.9	64.7
Specific mass hourly effective consumption of motor fuel $g_e$ , kg/(kW·h)	0.243	0.226	0.221
EG temperature in the exhaust manifold, °C	610	575	460
EG temperature before the neutralizer, °C	225	200	170
EG temperature after the neutralizer, °C	61	62	62
Excess pressure of EG in front of the neutralizer, mm H <sub>2</sub> O	1050	625	425
Excess pressure of EG after the neutralizer, mm H <sub>2</sub> O	205	100	45
Specific emissions of PM with EG flow before the neutralizer, g/kg of fuel	5.45	5.02	4.24
Specific emissions of PM with EG flow after the neutralizer, g/kg of fuel	3.03	2.76	2.22
Degree of purification of EG flow from PM, %	44.2	45.0	47.5
Concentration of NO <sub>x</sub> in the EG before the neutralizer, ppm	1650	–	–
Concentration of NO <sub>x</sub> in the EG after the neutralizer, ppm	1300	–	–
Degree of neutralization of NO <sub>x</sub> , %	21.2	–	–

warehouses, etc.), this problem becomes one of the primary ones. The wide distribution of PP with diesel RICE requires solving the task of neutralizing legislative regulated pollutants in the of their EG flow for diesel RICE operating mainly in stationary conditions. In this regard, work on the creation of a pollutant neutralization system in the EG flow for stationary diesel engines and during bench tests of diesel RICE is very relevant.

As is known [1–5], the main toxic components of the EG of diesel RICE are nitrogen oxides NO<sub>x</sub> and PM. Operation in stationary conditions makes it possible to significantly expand the search for NO<sub>x</sub> neutralization methods in the composition of EG. In well-known practice, several methods of cleaning EG from nitrogen oxides are used:

- oxidation-sorbtion,
- non-catalytic reduction,
- catalytic reduction,
- denitration of gases using irradiation.

The oxidation-sorption method is based on the preliminary oxidation of NO with subsequent absorption of NO<sub>2</sub> and N<sub>2</sub>O<sub>3</sub> by various absorbers.

Absorption of  $\text{NO}_x$  by solid absorbers, in particular silica gel and activated carbon, is very effective, and the degree of purification of EG reaches 98 %. However, these absorbers were not used in industry due to the scarcity of adsorbents and the high material and time costs of their regeneration.

Absorption of nitrogen oxides by liquids is widely used in industry [1, 3–5]. Nitrogen oxides of higher orders ( $\text{N}_2\text{O}_5$ ,  $\text{N}_2\text{O}_4$ ,  $\text{NO}_2$ ,  $\text{N}_2\text{O}_3$ ) are well soluble in water and other liquids, but  $\text{NO}$  is poorly soluble in fresh water, so it must be oxidized to higher order oxides. Oxidation of  $\text{NO}$  can be carried out by oxygen  $\text{O}_2$  or ozone  $\text{O}_3$  (in the gas phase, liquid phase, gas phase in the presence of water) or liquid oxidizers. Oxidation of  $\text{NO}$  in the gas phase with the help of oxygen is carried out with an excess concentration of 8–10 % by mass. The oxidation of  $\text{NO}$  by oxygen in the liquid phase (freshwater or nitric acid) is widely used since the amount of the liquid phase in the mass transfer process is two orders of magnitude smaller than the gas phase, and therefore technological operations are carried out in much smaller reaction volumes.

Liquid oxidizing agents with a predominant oxygen activity are often used: aqueous solutions of  $\text{KMnO}_4$ ,  $\text{NaClO}_2$ ,  $\text{HNO}_3$ ,  $\text{H}_2\text{O}_2$ , etc. As absorbents are used: water, aqueous solutions of  $\text{NH}_3$ ,  $\text{NaOH}$ ,  $\text{HNO}_3$ . The substances resulting from the neutralization reaction are either used as a final product or removed from the system by filtration, precipitating with an arbitrarily appropriate reagent.

The non-catalytic recovery method includes two stages. In the first stage,  $\text{NO}$  is oxidized to  $\text{NO}_2$  to obtain a more reactive nitrogen compound. The second stage is the non-catalytic reduction of  $\text{NO}_2$  to elemental nitrogen. The same methods and reagents described above are suitable for oxidation. In the second stage, reducing agents such as iodides, sulfides, ammonium sulfites, alkaline or alkaline earth metals are used, and oxidation inhibitors are added in the form of thiourea, ammonium polysulfide or thiosulfate or alkaline metal [1, 3–5].

Catalytic recovery methods have become the most widely used in industry. The process takes place on the surface of the catalyst in the presence of a reducing gas. As reducing gases,  $\text{NH}_3$ ,  $\text{CO}$ ,  $\text{H}_2$ , and  $\text{CH}_4$  are used for high-temperature reduction (700–1100 °C) or heating gas for selective catalytic reduction at a temperature of 200–500 °C. Catalysts are alloys of platinum group metals: Pd, Ru, Pt, Rh, or cheaper alloys containing Ni, Cr, Cu, Zn, V, Ce, and other components. Catalysts are used in the form of tablets, cylinders, or a cellular structure.

Catalysts based on Pt, Rh, and Pd have the highest activity, the content of which in the catalyst varies from 0.1 % to 2 % by mass. These catalysts provide a high level of gas purification at temperatures of 125–550 °C (residual  $\text{NO}_x$  concentration does not exceed 5 ppm). It is also recommended to use activated coke as a catalyst (with  $\text{NH}_3$  feeding into the gas mixture). This method allows cleaning at temperatures of 80–130 °C, which does not require additional treatment of EG. The degree of purification from  $\text{NO}_x$  is about 90 %.

Denitration of EG with the use of irradiation occurs with the use of radiation sources – laser, X-ray, or

radioactive radiation. At the same time, if  $\text{NH}_3$  is added to nitrous gases and the gases are treated with a beam of accelerated electrons, then solid products ( $\text{NH}_4\text{NO}_3$ ) are formed, which can be removed from the EG flow by mechanical methods. The addition of  $\text{ClO}_2$  or  $\text{O}_3$  to EG with simultaneous exposure to light with a wavelength of 2800–4300 angstroms from a high-pressure or low-pressure mercury lamp, a high-pressure gallium lamp, a fluorescent lamp, or a xenon lamp leads to the formation of  $\text{HNO}_3$ , which is removed in the absorber. Irradiation of gases containing  $\text{NO}_x$  with laser radiation or microwave irradiation from a source of 100–140 W and a frequency of 2450 MHz leads to the dissociation of nitrogen oxides into  $\text{N}_2$  and  $\text{O}_2$  [1, 3–5].

The analysis of the existing methods of neutralization of  $\text{NO}_x$  showed that the methods of catalytic reduction of  $\text{NO}_x$  to elemental nitrogen became the most widespread. At the same time, this method provides a high degree of purification with large volumes of purified gas and there is no need to dispose of the reaction products. However, several factors prevent the widespread use of catalytic  $\text{NO}_x$  neutralization methods in the EG flow of diesel RICE: firstly, the purified EG should not contain sulfur-containing substances that poison the catalyst, secondly, EG of diesel RICE is an aerosol and contains a significant amount of dispersed phase – PM, drops of motor oil, unburned motor fuel, which accumulate on the surface of the catalyst and reduce its activity. In addition, it should be taken into account that the preliminary purification of the EG flow of diesel RICE from the specified dispersed particles leads to a decrease in the EG temperature, and after filtration, to ensure favorable conditions for the catalyst, the EG must be heated to at least 150–250 °C (catalyst ignition temperature), which requires additional energy consumption. In addition, the most effective catalysts are made based on precious metals, which greatly increases the cost of executive devices of the pollutant neutralization system in the EG flow of diesel PP.

Liquid methods (oxidation-sorption and non-catalytic reduction) are used to clean the EG flow of stationary units with a volume flow of gas up to 2104 m<sup>3</sup>/h. The advantages of these methods are: low cost compared to the catalytic method; the ability to capture dispersed particles of the EG aerosol simultaneously with  $\text{NO}_x$  neutralization; carrying out cooling and washing of hot EG (increased fire and explosion safety). The disadvantages are a lower degree of  $\text{NO}_x$  neutralization, the need for periodic replacement of the spent WL solution, and its disposal or regeneration.

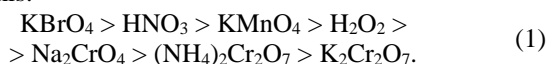
Based on the results of the analysis of existing methods of purification EG from  $\text{NO}_x$ , it is advisable to use liquid neutralization of EG (oxidation-sorption method and non-catalytic reduction method) for diesel RICE operating in stationary conditions.

Fresh technical water is the simplest, cheapest, and non-deficient absorber of harmful impurities.  $\text{NO}_2$  easily dissolves in it with the addition of nitric acid.

Active  $\text{NO}_x$  absorbers can be solutions that have an alkaline reaction (alkalis, bases). The alkaline cleaning method is quite widely used in the industrial production of nitric acid. At the same time, the EG contain an equimolar (1 : 1) mixture of oxide and  $\text{NO}_2$  [1, 3–5].

However, almost 90 % of the NO<sub>x</sub> contained in the diesel fuel of diesel RICE consist of NO, which is poorly soluble in water and almost does not interact with alkalis. In addition, such EG contain CO<sub>2</sub>, the concentration of which is two orders of magnitude higher than NO<sub>x</sub>. In the case of using the alkaline method, most of the reagent is spent on CO<sub>2</sub> neutralization. Therefore, it is impractical to use the alkaline method for the neutralization of EG of diesel RICE.

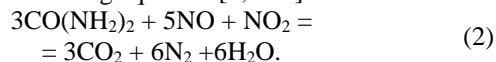
Since NO is more inert than higher oxides of nitrogen, it is necessary to convert it into oxides of a higher order, which show greater reactivity in chemical reactions. In chemistry, several liquid oxidizing agents are known, which are superior in their activity to oxygen. This series in decreasing oxidizing activity looks like this:



This series was analyzed by the values of the standard electrode potentials, which characterize the oxidizing abilities of the reactants. Potassium permanganate (KMnO<sub>4</sub>) in an acidic medium was chosen as an oxidizing agent for NO<sub>x</sub> in a liquid neutralizer for research based on oxidizing activity, availability, and cost, based on previous experimental research.

The laboratory installation on which the research was executed consisted of a glass (the so-called «reactor») filled with a liquid through which part of the EG flow from the D21A1 diesel engine bubbled. The volume flow rate of the gas flow was controlled by a flow meter – an improved gas meter with an optical sensor with a signal flow to a stopwatch chronometer. Sampling of EG for NO content was carried out before the «reactor» and after it with a «HORIBA» gas analyzer. Reaction mixtures of different concentrations and component compositions were tested for different regimes of operation of the D21A1 diesel engine on a motor test bench.

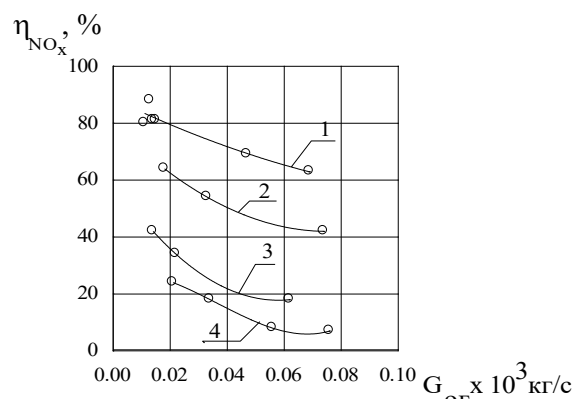
In addition to the oxidative absorption of NO<sub>x</sub>, the method of non-catalytic reduction in the liquid phase was also tested [1, 3–5]. An aqueous solution of carbamid (urea) with a concentration of 10 % by mass with various additives was used as the main reagent. At the same time, the chemisorption process proceeds according to the following equation [1, 3–5]:



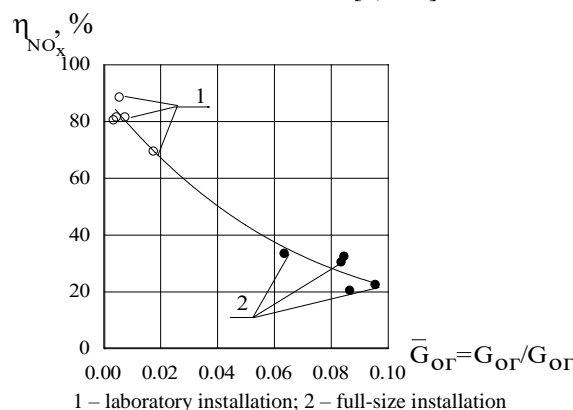
This method is of interest because it gives non-toxic reaction products at a low cost and the availability of reagents.

The main results of the performed experimental studies are shown in Fig. 8. It can be seen from the graph that the highest degree of purification of the EG flow from NO<sub>x</sub> (80–90 %) showed an aqueous solution of potassium permanganate in the presence of nitric acid. This composition was tested on a full-size installation with a D21A1 diesel engine (EG was completely passed through the appropriate size «reactor»).

In Fig. 9 presents the results of experimental studies carried out on laboratory and full-scale installations with a D21A1 diesel engine, with an aqueous solution of KMnO<sub>4</sub>(1 %) + HNO<sub>3</sub>(0.4 %), on which G<sub>EGmax</sub> is the maximum mass hourly flow of EG of the D21A1 engine



1 – water solution of KMnO<sub>4</sub> + HNO<sub>3</sub>; 2 – water solution of KMnO<sub>4</sub> + H<sub>2</sub>SO<sub>3</sub>; 3 – water solution of CO(NH<sub>2</sub>)<sub>2</sub> + SnCl<sub>2</sub> + HNO<sub>3</sub>; 4 – H<sub>2</sub>O  
Figure 8 – Dependents of the degree of neutralization of NO<sub>x</sub> from EG mass second consumption for different chemical adsorbers [1, 3–5]

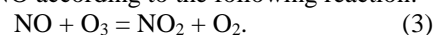


1 – laboratory installation; 2 – full-size installation  
Figure 9 – Efficiency of neutralization of NO<sub>x</sub> by the water solution of KMnO<sub>4</sub> + HNO<sub>3</sub> [1, 3–5]

in the experiment. From the obtained results, it can be seen that the degree of neutralization of NO<sub>x</sub> in the EG flow depends on the hourly mass flow velocity of EG. At low volumetric velocities, the NO<sub>x</sub> neutralization process is determined primarily by the kinetics of the chemical reaction itself. With an increase in the value of the mass hourly consumption of EG, the process of neutralization is significantly influenced by the hydrogasodynamic processes taking place in the «reactor».

The obtained results were confirmed in the process of factory tests of the EG neutralization system for the KamAZ-740 diesel engine at the test station of the Science Technical Center: the degree of NO<sub>x</sub> neutralization in the EG flow with an aqueous solution of KMnO<sub>4</sub>(1 %) + HNO<sub>3</sub>(0.4 %) is 21.2 % [1, 3–5].

The method of liquid neutralization of NO<sub>x</sub> in the EG flow using ozone is promising. Ozone in the gas phase oxidizes NO according to the following reaction:



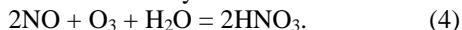
At the same time, only one of the three oxygen atoms included in the ozone molecule is usefully used. Intensification of the oxidation of NO to NO<sub>2</sub> can be achieved by carrying out the process in the liquid phase. NO<sub>2</sub> and O<sub>2</sub> are quite well absorbed by water.

It is known that ozone exhibits unique properties in heterophase water systems. The high electron affinity of ozone leads in aqueous solutions to the formation of the ozonide ion radical O<sup>3-</sup>, which with the participation of water molecules and hydroxide ions gradually decom-



poses with the formation of several intermediate radicals to oxygen:  $O_3^- \rightarrow O_2^- \rightarrow OH^* \rightarrow HO_2^* \rightarrow O_2$  oxidation reactions are used:  $NO + O_3 = NO_2 + O_2$ ;  $NO + HO_2 \cdot = HNO_3$ ;  $NO_2 + OH = HNO_3$ , which allows you to significantly speed up the absorption process.

At the same time, it is important that during oxidation in the liquid phase of the oxidation reaction, all three oxygen atoms are usefully used:



Experimental studies were executed at the laboratory facility to evaluate the effectiveness of  $NO_x$  neutralization in the EG flow using  $O_3$ . Ozonated air bubbled through the water column, saturating it with dissolved ozone. Then a flow of EG, taken from the exhaust system of the KamAZ-740 diesel engine, was passed through the ozonized water. At a concentration of  $NO_x$  in EG of 2450 ppm, the degree of neutralization was 59.2...34.7%. The decrease in the degree of neutralization is explained by the activation of the reagent, i.e. decrease in the concentration of ozone in water when bubbling the flow of EG through it. However, due to the lack of a high-performance ozonator, it was not possible to research a full-scale installation [1, 3–5].

Thus, based on the analysis of the results of the performed studies, the following conclusions can be drawn.

1) The choice of the method of neutralization of  $NO_x$  in the flow of EG of diesel RICE significantly depends on the operating conditions and specific requirements for the degree of neutralization of EG.

2) A simple, economical, and sufficiently effective method of liquid neutralization can be used for diesel RICE operating in stationary conditions.

3) The degree of liquid neutralization of  $NO_x$  depends both on the chemical composition of the solution and on the hourly mass flow rate of EG through the «reactor».

4) The method of liquid  $NO_x$  neutralization using ozone is the most promising for diesel RICE operating in stationary conditions.

#### 10. Analysis of the field of application of liquid neutralization of pollutants in the composition of EG of diesel RICE

The neutralization of EG of diesel RICE has some features, as such EG contains more oxygen and has a lower temperature compared to EG of gasoline RICE. The use of triple-action neutralizers in the exhaust system of diesel engines, which are widely used in gasoline engines, is impossible due to the large values of the excess air coefficient  $\alpha$  – from 1.3 (the smoking limit in the maximum torque regime) to 18...20 (in the minimum idle regime). A significantly higher emission of PM and sulfur oxides in the EG flow of diesel RICE compared to the EG of gasoline RICE complicates the use of EG filters and catalytic converters in them, which is caused by the clogging of PM filters and “poisoning” of the catalytic layer of the converter with sulfur compounds. At present, catalytic oxidation and reduction neutralizers of EG diesel RICE have found application [1, 3–5].

Thermal neutralizers, which carry out post-combustion of products of incomplete combustion of fuel,

are mainly intended to reduce the emission of  $CH_x$  and CO hydrocarbons. In addition, thermal neutralizers oxidize  $SO_2$  to  $SO_3$  and aldehydes. The temperature in the reaction chamber of these neutralizers is 900...1000 K. At high temperatures, partial afterburning of PM is also observed.

To reduce the emission of PM with the flow of EG of diesel RICE, their filtration is also actively used. The main mass of PM has a linear size of 0.05...1.0  $\mu m$ , therefore filters are used with FE made of metal ceramics, metal fibers, and metal mesh sintered with metal powder. Centrifugal and inertial traps and electrostatic filters are also known. Ceramic DPF have found the greatest use.

In recent years, plasma neutralization of pollutants in the EG flow of diesel RICE has been developed, which is based on the treatment of the EG flow with low-temperature plasma, which is created with the help of various electric discharges (corona, barrier, surface, smoldering, etc.). Under these conditions, chemical reactions of the transformation of toxic components of EG ( $NO_x$ , CO, CH, PM,  $SO_x$ , etc.) into harmless or less harmful ones occur. A promising technical solution is the combination of low-temperature plasma with catalysts, which allows for a significant increase in the efficiency of the method.

As shown in this study, the method of liquid neutralization of pollutants in the EG flow of diesel RICE is the simplest and most economical way of physicochemical influence on EG of diesel RICE and consists in passing EG through a layer of WL or spraying WL in the flow of EG. At the same time, harmful substances are dissolved or trapped in the EG flow. Water or aqueous solutions of chemical reagents are used as WL. Water intensively absorbs  $CO_2$  and  $NO_2$ , PM, aromatic hydrocarbons,  $SO_x$ , aldehydes, and other water-soluble components of EG. The temperature of WL in liquid neutralizers is usually equal to 300–320 K [1, 3–5].

Systems of liquid neutralization of pollutants in the EG flow are also used for marine diesel engines, where offshore water is used as the WF, and the mass and overall dimensions do not significantly affect the choice of the neutralization method.

Combined multi-stage neutralization systems, which include the degree of liquid neutralization of EG, are used for diesel RICE land-based MV operating in areas with limited air exchange and in closed rooms (for example, in workshops, greenhouses, holds, etc.), where environmental requirements are decisive.

For special underground equipment and trucks with diesel engines, based on the conditions for meeting the fire and explosion safety requirements, the EG liquid neutralizer is a mandatory component of the used neutralization systems. In most cases, this is the catalytic and liquid stage of neutralization of EG.

During the operation of liquid neutralization systems of EG diesel RICE WF, which can be considered as a replaceable FE, it is necessary to dispose of it. Several variants of the organization of this technological process are possible: centralized at special treatment stations; directly at the place of operation of the neutralization system and a combined option. Moreover, each of them determines the choice of the method of cleaning WF, as

well as the financial and material costs for their implementation.

The advantages of liquid neutralization of pollutants in the EG flow of diesel RICE determine the scope of application of this method, especially in those cases where these qualities are decisive. This ensures liquid neutralization of pollutants in the EG flow of diesel RICE its permanent “technical niche”.

In modern conditions, the most effective application of liquid neutralization of EG is for test stations of diesel RICE, for autonomous stationary diesel PP, and diesel RICE MV, which are used in places with limited air exchange and closed rooms, as well as for ship diesel PP.

Liquid EG neutralizers are a mandatory component of neutralization systems for special underground installations with diesel RICE, for diesel trucks, and special self-propelled equipment that works in an explosive environment (mines, etc.). Therefore, for such specific operating conditions, liquid neutralization of EG of diesel RICE will be needed in the future as well.

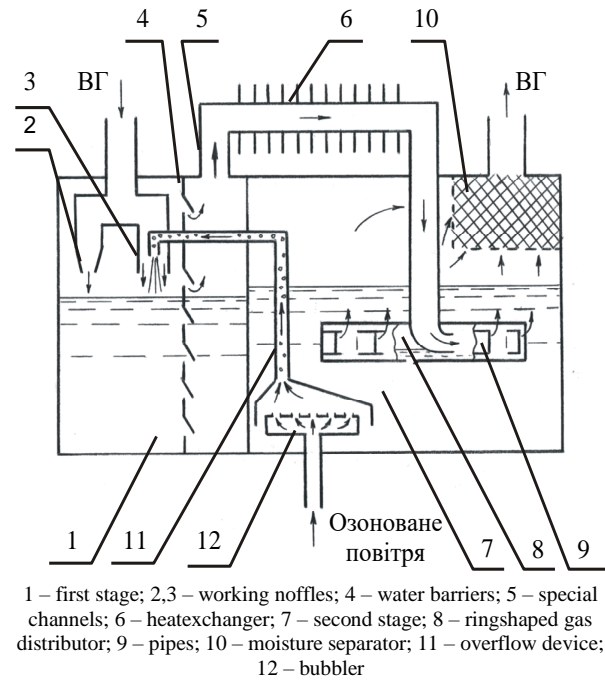
Improvement of the liquid neutralization of EG of diesel RICE by overcoming and reducing the influence of the method’s shortcomings, as well as increasing the efficiency of neutralization of the most harmful components of EG of diesel RICE – PM and NO<sub>x</sub> will ensure the feasibility of further use of this technology [1, 3–5].

One of the important factors for the successful operation of liquid neutralization systems of EG of diesel RICE is the need to develop an effective and economical system for cleaning WL with subsequent utilization of the components extracted from EG.

### 11. Improvement of the design of the diesel liquid neutralizer of EG diesel RICE

The main element of the liquid gas neutralization system developed in the research of the author’s team is a diesel liquid neutralizer (DLN), the schematic diagram of which is presented in Fig. 10 [1, 3–5]. The DLN was made in two stages, which made it possible to increase the efficiency of neutralization of EG of diesel RICE due to the use of several physical processes of EG purification and by intensifying the interaction of gas and liquid phases, and also allowed to significantly reduce the removal of WL and chemical reagents with the flow of purified EG in the AA.

There is technical fresh water in the DLN. The DLN is two partially filled WL metal containers (stages) [1, 3–5]. In the first container 1 (see Fig. 9) there is a collector with working nozzles 2, and 3 that form a gas flow. Flowing in jets from the vertically located nozzles 2, and 3, EG hit the surface of the liquid, and then, bypassing water-deflecting partitions 4, through special channels 5, which are equipped with a heat exchanger 6, they are sent to the second container 7. Here, EG are fed into the annular gas distributor 8 and, passing through are located on its side surface of the nozzle 9, bubble in the WL. Next, EG through the moisture separator 10, which prevents the removal of WL, is released into the atmosphere. The containers are also connected by an overflow device 11, which is designed to return from the second stage to the first (through the nozzle 3) the working fluid carried out with the first flow of EG,



1 – first stage; 2,3 – working nozzles; 4 – water barriers; 5 – special channels; 6 – heatexchanger; 7 – second stage; 8 – ringshaped gas distributor; 9 – pipes; 10 – moisture separator; 11 – overflow device; 12 – bubbler

Figure 10 – Scheme of two-staged diesel liquid neutralizer of EG [1, 3–5]

together with ozonated air, which is supplied through the bubbler 12.

The principle of action of the developed DLN is based on impact-inertial and inertial-bubbling liquid neutralization of EG. The ozone method is used to neutralize nitrogen oxides [1, 3–5].

As is known, the effectiveness of the inertial method is determined by the mass characteristics of the PM removed from the EG flow. In this case, it is PM together with hydrocarbons adsorbed on them. When the temperature of the blood vessels decreases, coagulation of PM occurs. The velocity of PM coagulation is determined by the concentration and size of PM, the degree of their polydispersity, shape, the presence of adsorbed films, as well as flow tribulation and the degree of temperature reduction of the EG flow. In general, the cleaning of dispersed PM is based on the violation of their aggregative and kinetic stability and their removal from the EG flow by the force of the inertial field.

Due to the hydrophobicity and small size of PM, their effective capture in the DLN is largely due to the effect of volume condensation of water vapor from the EG. Bulk condensation occurs in special points – condensation centers. With the rapid expansion of EG, they cool down and PM become heterogeneous active centers and, acting as nuclei, adsorb a thin film of liquid on their surface. At the same time, the particle covered with liquid behaves as a drop of equivalent size (with the corresponding hydraulic diameter). The hydrophilicity of the particles formed in the process of condensation, as well as a significant increase in their mass and size due to the enveloping PM layer of water and due to the coagulation process, contribute to the effective capture of PM.

In the two-stage DLN, the purification of EG from PM occurs in the following way. EG with a certain velocity flow out in vertical jets through the narrowing nozzles 2 (see Fig. 9) and the ejector nozzles 3, the lo-

wer sections of which are located above the surface of the WL. When passing through the nozzles 2, and 3, the velocity of EG increases, and after leaving the nozzles, their velocity decreases sharply, and with rapid expansion, they cool down, which leads to condensation and coagulation.

The EG jets flowing out of the nozzles hit the surface of the WL and, due to the collision with the WL, PM is removed from the EG flow. At the same time, a layer of foam and mist is formed. Breezes are raised by the EG flow to different heights and, depending on their dispersion, are classified as EG flow.

Passing through nozzles 3, connected to the overflow device 11, the EG ejects the WF from the second stage. This achieves both the neutralization of EG by introducing WL into the EG flow, and the return of WL carried over from the first stage, that is, the internal circulation of WL is ensured. It should be noted that in this way it is possible to overflow the WL from the second stage, where the EG pressure is lower than in the first stage.

After hitting the free surface of the WL, the EG flow together with the drops and vapors of the WL, sharply changing its direction of movement, bypasses the water baffles 4, where the drops and breezes are partially removed, and through the channels 5, through the heat exchanger 6, enters the gas distributor 8 (see Fig. 9). In the heat exchanger, EG is additionally cooled and WL vapors are condensed. Inside the box-shaped toroidal gas distributor, EG is intensively mixed with WL, forming a layer of foam, and then moves along the annular closed circuit of the toroidal collector. At the same time, PM covered by a layer of water, together with WL, are pressed against the side surface of the toroidal collector by centrifugal forces and absorbed by WL, and the remaining WL vapors from the first stage condense. It should be noted that the design of the gas distributor 8 ensures high efficiency in all, including transitional, regimes of operation of the diesel engine.

After interacting with the WL inside the gas distributor, the EG passes through the tangential nozzle 9 located on its side surface and bubbles into the WL of second stage. In the end, EG passes through the zone of foam and breezes, which are formed during bubbling, and through the moisture separator 10 are sent to AA.

Thus, using effective hydrogasodynamic processes for purification the EG aerosol from PM, the developed DLN provides adsorption, condensation, capture of finely dispersed PM, and filtration of EG from them.

In the two-stage DLN,  $\text{NO}_x$  neutralization occurs in the heterophase process of nitrogen oxide absorption by the ozone method [1, 3–5]. Ozonated air from the ozonator (not shown in Fig. 9) is supplied through the bubbler 12 to the second stage 7 and bubbles in the working liquid, saturating it with ozone. Then, through the overflow device 11 and nozzle 3, the ozonated air together with the ejected WL from the second stage enters the first stage and interacts with the EG. At the same time, taking into account the fact that in the first stage, a layer of foam is formed upon the impact of EG on the uniform surface of WL, the conditions for an effective heterophase process of  $\text{NO}_x$  absorption by the ozone method are provided.

Next, EG together with drops and vapors of WL, as well as ozone, which partially did not react, from the first stage through channels 5 through the heat exchanger 6 enter the gas distributor 8 and, after interaction with WL inside the toroidal gas distributor, bubble in the second stage. At the same time, due to the use of ozone, which partially did not react, and because the WL of the second stage is saturated with ozone with the help of the bubbler 12, additional purification of EG from  $\text{NO}_x$  takes place.

In this way, the intensification of the  $\text{NO}_x$  oxidation process by ozone in the liquid phase is ensured in the first stage. The nitric acid formed remains in solution. In the second stage, additional neutralization of  $\text{NO}_x$  is ensured and ozone, which did not react in the first stage, is prevented from being carried into the AA, which is very important given the aggressiveness of ozone.

The effectiveness of the two-stage neutralization of  $\text{NO}_x$  in the DLN is due to the intensive interaction of the gas and liquid phases, as well as a significant increase in the surface area and time of their contact.

It should be noted that the joint work of the two stages as part of the DLN provides a greater efficiency of neutralization of EG of diesel RICE than the simple sum of their positive effects when working separately, that is, there is a synergistic effect.

The calculation of the main elements of the design of the DLN is carried out taking into account the range of changes in the hydrodynamic and environmental parameters of the EG flow in different operating regimes of the RICE and based on the conducted studies of the liquid neutralization of EG, which showed that several factors affect the efficiency of cleaning EG from PM [1, 3–5]: the velocity of EG outflow from the nozzles, the distance from the nozzle cut to the free surface of the WL, the temperature of the EG and WL, the design of the annular gas distributor; and for  $\text{NO}_x$  liquid neutralization – the concentration of chemical reagents and the relative velocity of EG.

The methodology for calculating the main elements of the design of the DLN is based on the condition of ensuring the minimum, determined in previous studies, the effective speed of the EG along the entire path of the neutralizer. This makes it possible to achieve both a high degree of neutralization of EG and a minimum value of HR.

The mass and overall parameters of the DLN are determined based on the power of the diesel engine and its purpose (model of its exploitation). Two basic versions of the design of the DRN have been developed: stationary and for MV.

Tests of the developed EG neutralizer carried out in factory conditions confirmed its efficiency [1, 3–5]. These tests of the DLN as a part of the stationary system of neutralization of EG with the KamAZ-740 diesel engine showed that the DLN allows for significantly reduced emissions of PM, carries out  $\text{NO}_x$  neutralization, reduces the temperature of EG to 62 °C, weakens the intensity of the smell of EG, reduce the noise level of EG emission of a diesel RICE while simultaneously providing the required minimum HR.

The HR of the DLN and the pollutant neutralization system in the EG flow of the diesel RICE is generally

less than the HR of the stock muffler, which allows the neutralization of the EG without additional power withdrawal of the diesel RICE, therefore the DLN can be installed instead of the standard muffler.

Thus, the developed DLN for EG of diesel RICE provides an effective reduction of the main toxic components of EG – PM and NO<sub>x</sub> and makes it possible to equip autonomous, created based on DRN, EG neutralization installations of both stationary PP, test stations, and boxes, as well as MV working in areas with limited air exchange and in closed rooms (for example, greenhouses, workshops, holds, as well as in mines and mining operations).

The schematic diagram of the stationary system of liquid neutralization of pollutants in the EG flow of diesel RICE is presented in Fig. 11. Such a system consists of a DLN 1, an air ozonator 2, two tanks of a settling tank 3 as part of a system for collecting and cleaning WL from PM and systems for draining and pumping WL. The transport variant of the system differs in that the DLN together with the air ozonator are located directly on the MV, and other parts of the system are installed stationary at the place of collection and purification of WL. The main element of the EG neutralization system is the DLN, the schematic diagram of which is presented in Fig. 10 [1, 3–5].

The methodology for calculating the main elements of the DLN design is based on the condition of ensuring the minimum, determined in previous studies [1,3–5], the effective velocity of the EG flow along the entire DLN tract. This makes it possible to achieve both a high degree of neutralization of EG and minimal HR.

The dimensions and number of nozzles 2, 3 (see Fig. 9) are determined under the conditions of ensuring a rational flow rate of EG from the nozzles in the calculated regime of operation of the diesel RICE (nominal power regime) and minimum – in the minimal idling regime. The number of nozzles is determined for design reasons.

Mass consumption of EG in the calculation operational regime [1, 3–5]:

$$G_{eg} = \sum F_c \sqrt{\frac{2\kappa}{\kappa - 1} \frac{P_{ex}^2}{R_{eg} T_{ex}} \times \left[ \left( \frac{P_1}{P_{ex}} \right)^{\frac{2}{\kappa}} - \left( \frac{P_1}{P_{ex}} \right)^{\kappa+1} \right]}, \text{ kg/h}, \quad (5)$$

where  $\sum F_c$  – total cross-sectional area of nozzles, m<sup>2</sup>;  $\kappa$  – index of adiabatic of EG;  $P_{ex}$  – pressure of EG vice in front of DLN, Pa;  $R_{eg}$  – gas constant of EG, kJ/(kg·K);  $P_1$  – pressure of EG in first stage of DLN, Pa.

The total pressure drop for both DLN stages is specified  $\sum \Delta P = \Delta P_1 + \Delta P_2$ , which should not exceed the gas-dynamic resistance of the RICE standard muffler.

Pressure of EG vice in front of DLN:

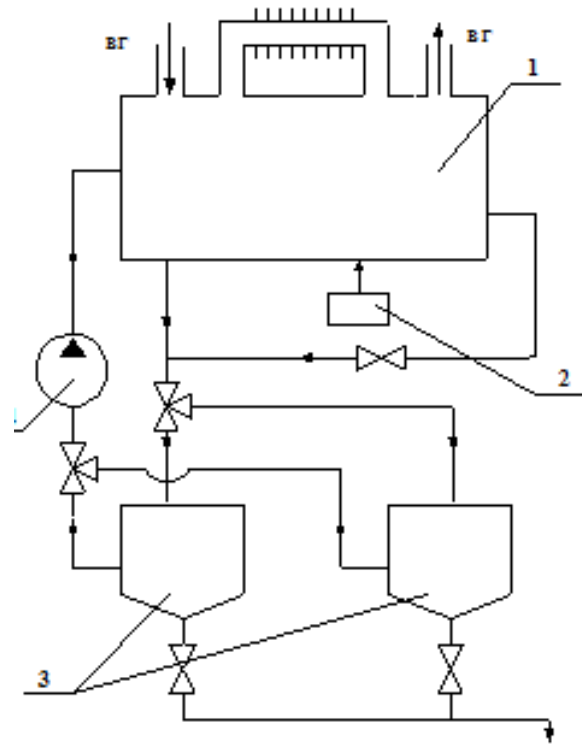
$$P_{ex} = P_H + \sum \Delta P, \text{ Pa}, \quad (6)$$

where  $P_H$  – normal atmospheric pressure, Pa.

Pressure of EG in first stage of DLN:

$$P_1 = P_H + \Delta P_2, \text{ Pa}. \quad (7)$$

Diameter of nozzles 2 and equivalent diameter of nozzles 3 [1, 3–5]:



1 – liquid neutralizer of EG; 2 – air ozonator; 3 – settling tank; 4 – transfer pump

Figure 11 – Scheme of liquid neutralization of EG of diesel RICE [1, 3–5]

$$d_c = \sqrt{\frac{4 \sum F_c}{\pi m}}, \text{ m}, \quad (8)$$

where  $m$  – the total number of nozzles 2 and 3.

Taking into account the given consumption of EG in the operational calculation regime of the diesel RICE, by jointly solving equations (5), (6), (7) and (8), the diameter of the nozzles  $d_c$  is determined.

Nozzles 3 are calculated as ejectors, taking into account the cross-sectional area of the ejecting EG determined by the equivalent diameter and the return from the 2<sup>nd</sup> stage (through nozzle 3) of WL together with ozonated air.

Velocity of EG flow from nozzels [1, 3–5]:

$$W_{eg} = \frac{G_{eg} R_{eg} T_{ex}}{m \frac{\pi d_c^2}{4} P_{ex}}, \text{ m/s}. \quad (9)$$

Similarly, the velocity of EG flow from the nozzles in the RICE idling regime is calculated.

The calculated velocity of EG flow from the nozzles should be within the limits of the velocity of EG flow defined in [1, 3–5].

The diameter of the special channels 5, through which the EG is sent to the 2<sup>nd</sup> stage and supplied to the annular gas distributor 8 [1, 3–5]:

$$D = \sqrt{\frac{2 G_{eg} R_{eg} T_1}{\pi W_{eg}^2 P_1}}, \text{ m}, \quad (10)$$

where  $T_1$  – temperature of EG in 1<sup>st</sup> stage of DLN, K.

The dimensions of the toroidal gas distributor 8 are determined by its design and the requirement to ensure the optimal velocity of EG based on the minimum cross-sectional area of the annular gas distributor, which

should be 1.5 times larger than the cross-sectional area of special channels 5 [1, 3–5].

The mass and overall parameters of the DLN are determined based on the power of the diesel RICE, its purpose (stationary or transport), and the requirements of the specified frequency of replacement of the WL. The amount of WL in the first stage should ensure the optimal distance from the nozzle cut to the free surface of the WL, and in the second stage, the level of WL should be at the same level as the annular gas distributor [1, 3–5].

The productivity of the air ozonator 2 is calculated from the condition of the need for the necessary ozone content for the complete neutralization of  $\text{NO}_x$  in the EG [1, 3–5].

The dimensions and capacity of the sump 3 of the collection and purification system of WL and the parameters of the drainage and pumping systems of WL are determined by the developed technology of WL cleaning and the number of simultaneously connected DLN to the clarifier. It should be noted that the substances obtained in the process of cleaning WL may later act as raw materials during disposal. For example, soot from EG of diesel RICE can be used in the latest nanotechnologies [1, 3–5].

### Conclusions

Thus, the results of research on the analysis of literary sources regarding the relevance of creating a complex EPT against the negative impact of PP with diesel RICE, including ERV and SE as part of the divisions of the SES of Ukraine, which will be assigned a wide range of tasks as in wartime, and in the period of

post-war reconstruction of the country, based on improved executive devices, in particular, DPF with a liquid working body.

In the study, for the first time the multi-level classification of methods and means of influence on the EG flow of diesel RICE as executive devices of the corresponding EPT against the negative antropogenic impact of the PP with such RICE with different degrees of moral and physical wear and tear during their exploitation, in particular ERV and SE, which are on operational duty of units of the SES of Ukraine, has been improved and is supplemented by the appropriate hierarchical decimal classifier. The improvement consists in the fact that the classification and classifier indicate the place of DPF with a liquid working body, which can have a complex chemical and physical effect on the processed EG flow.

Also for the first time the design of the DPF with a liquid working body has been improved, which can have a complex chemical and physical effect on the EG flow from the PP with diesel RICE with different degrees of moral and physical wear during their exploitation, in particular, the ERV and SE, which are on operational duty of units of the SES of Ukraine. The improvement consists in the application of an ozone-reagent method of processing the EG flow in order to neutralize  $\text{NO}_x$  in them, the mechanical-inertial effect on the flow of sharply cooled EG, which bubbles through the liquid working body of the DPF, in order to purification them from PM, as well as suppressing exhaust noise and thermal contamination of environment components.

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### Кондратенко О. М., Краснов В. А., Семикін В. М.

#### МІСЦЕ ФТЧ З РІДИННИМ РОБОЧИМ ТІЛОМ У КЛАСИФІКАЦІЇ ТЕХНОЛОГІЙ ЗАХИСТУ АТМОСФЕРНОГО ПОВІТРЯ ВІД КОМПЛЕКСНОГО НЕГАТИВНОГО ВПЛИВУ ЕНЕРГОУСТАНОВОК З ПОРШНЕВИМ ДВЗ

У статті, яка відображає результати власного дослідження колективу авторів, метою якого було вдосконалення класифікації методів та засобів очищення потоку ВГ поршневого ДВЗ від поллютантів як технологій захисту навколишнього середовища шляхом включення у неї виконавчих пристроїв для комплексного впливу на поллютанти та чинники енергетичного забруднення атмосферного повітря як складової довілля, зокрема ФТЧ з рідинним робочим тілом, послідовно вирішено наступні задачі щодо вдосконалення розробленого раніше, наведеного у відкритому друку та апробованого на низці науково-технічних конференцій міжнародного рівня конструкції виконавчого пристрою ТЗНС комплексної дії та вдосконалення наукового продукту упорядкування інформації – ряду взаємопов'язаних багаторівневих класифікацій – шляхом встановлення місця пристрою у цих класифікаціях, а саме: аналіз літературних даних щодо чинників екологічної безпеки, джерелом яких є поршневі ДВЗ в складі ЕУ; аналіз класифікації способів та засобів зниження токсичності ВГ дизельних поршневих ДВЗ; аналіз класифікації способів і засобів очищення ВГ дизельних поршневих ДВЗ від ТЧ; аналіз механічних пристроїв і систем очищення ВГ дизельних поршневих ДВЗ від ТЧ; аналіз хімічних пристроїв і систем очищення ВГ дизельних поршневих ДВЗ від ТЧ; аналіз гідродинамічних способів очищення ВГ дизельних поршневих ДВЗ від ТЧ та інших чинників екологічної безпеки; аналіз способів регенерації ФТЧ з рідинним робочим тілом; аналіз експериментального визначення ефективності застосування ФТЧ з рідинним робочим тілом; аналіз нейтралізації оксидів азоту у ФТЧ з рідинним робочим тілом; аналіз озонного методу нейтралізації оксидів азоту у ВГ дизельних поршневих ДВЗ; аналіз області застосування рідинної нейтралізації поллютантів у складі ВГ дизельного поршневого ДВЗ та вдосконалення конструкції дизельного рідинного нейтралізатора ВГ дизельного поршневого ДВЗ. Об'єктом дослідження є класифікація методів та засобів очищення потоку ВГ ПДВЗ від поллютантів як технологій захисту навколишнього середовища. Предметом дослідження є місце виконавчих пристроїв для комплексного впливу на поллютанти та чинники енергетичного забруднення атмосферного повітря як складової довілля, зокрема ФТЧ з рідинним робочим тілом, у об'єкті дослідження. Наукова новизна результатів дослідження полягає в тому, що набула подальшого розвитку класифікація методів та засобів очищення потоку ВГ поршневого ДВЗ від поллютантів як технологій захисту навколишнього середовища шляхом включення у неї виконавчих пристроїв для комплексного впливу на поллютанти та чинники енергетичного забруднення атмосферного повітря як складової довілля, зокрема ФТЧ з рідинним робочим тілом. Практичне значення результатів дослідження, полягає у тому, що вдосконалена і доповнена у дослідженні класифікація придатна для більш детального впорядкування інформації та обґрунтування актуальності розробки окремих комплексних інноваційних технологій захисту навколишнього середовища та встановлення вертикальних і горизонтальних структурно-логічних взаємозв'язків між об'єктами класифікації.

**Ключові слова:** технології захисту навколишнього середовища, екологічна безпека, електростанції, поршневі двигуни внутрішнього згоряння, дизельний фільтр твердих частинок, класифікація, тверді частки, оксиди азоту, незгорілі вуглеводні, чадний газ, шум, теплове забруднення.

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