EXPERIMENTAL STUDY OF THE SYSTEM "SOURCE OF EXHAUST GAS - STORAGE CAPACITY"

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Resume

The article presents the results of testing the validity of the hypothesis about the possibility of isolating the exhaust gases of the internal combustion engine (exhaust gas source). The objective was to conduct an experimental study of the "exhaust gas source - storage tank" system. In the experimental study, the following was performed: establishment of influencing factors and output parameters; selecting the number of experiments; methods and means of measurement; conducting an experiment at the stand.

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1 Introduction

The main measures to improve the environmental safety of vehicles can be divided into two groups - cleaning and isolation of exhaust gases (EG). Currently, a huge number of measures for exhaust gas purification are known and studied, and methods for isolating exhaust gases have not been sufficiently studied and covered in the literature. The review and analysis show that basically all the methods for reducing harmful emissions from diesel exhaust gases today are based on cleaning methods, and methods for isolating exhaust gases are not currently being considered. Thus, it is necessary to further search for the new design solutions to reduce harmful emissions from diesel locomotives by insulating them.

The main goal of the experimental study of the "exhaust gas source - storage tank" system is to test the validity of the hypothesis about the possibility of isolating the exhaust gases of the internal combustion engine (exhaust gas source) by determining the time of filling the storage tank (experimental stand) with gases depending on the engine rotation speed.

The experimental study included the following stages [1]:

1. *Establishment of influencing factors and output parameters.* As an influencing factor, we take the load mode of the internal combustion engine, characterized by the rotation speed *(n, rpm)*. As an output parameter we take the time of filling the storage tank *(t, min)* of the experimental stand with exhaust gases from the internal combustion engine.
2. *Selecting the number of experiments.* The object of experimental research is the "Exhaust gas source - storage tank" system reproduced on an experimental stand, which is designed to solve the stated purpose of the experiment. This object can be represented as a "Black box" of an one-factor experiment, where the influencing factor enters - rotation speed (n, rpm), and the output parameter comes out - time to fill the storage tank (t, sec). Thus, registration of the output parameter in an one-factor experiment is carried out by considering the influence of one factor and determining one value of the output parameter. Based on the above conditions, and in accordance with the Methodology of rational planning of experiments [2], to conduct the experiment it is necessary to first carry out $N=1^1=1$ parallel experiments for each loading mode of the internal combustion engine, according to the

dial of the measuring device (tachometer) of the experimental stand:
- experiment No. 1 - 1st mode - 900 rpm;
- experiment No. 2 - 2nd mode - 1000 rpm;
- experiment No. 3 - 3rd mode - 1100 rpm;
- experiment No. 4 - 4th mode - 1200 rpm.

3. *Methods and means of measurement.* Measurement methods: to measure the time of filling the storage tank, a method is used that is based on measuring time intervals (with a stopwatch) of filling the tank with exhaust gases under different operating modes of the internal combustion engine; to maintain the safe operation of the experimental stand, it is necessary to monitor the pressure and temperature in the system; when measuring pressure, a method based on mechanical pressure measurement (manometer) is used; a thermometer is used to measure temperature. When conducting experiments, the following measuring instruments are used: stopwatch, manometer, and thermometer. The measuring instruments used during the experiment must be verified in accordance with the requirements of the metrology rules. When carrying out measurements, the possibility of exhaust gas leakage must be excluded.
4. *Conducting an experiment at the stand.* All the experiments were carried out on an original experimental stand to study the system "exhaust gas source - storage tank" (Figure 1, *a*), according to the developed Experimental Work Program [1]. The operating diagram of the experimental stand is shown in Figure 1, *b*.

Technical characteristics of the experimental stand (Figure 1):

- ICE - 1.9-liter diesel from a Volkswagen car;
- compressor - from a ZIL-130 car;
- connecting transmission - belt;
- storage tank - consists of 3 oxygen cylinders with a total volume of 0.12 cubic meters;
- cooling container - 0.04 cubic meters;
- tachometer - from a Volkswagen Golf III;
- thermometers - No. 1 from 0 to 350 ^{0}C, No. 2 from 0 to 120 ^{0}C;
- manometers - No. 1 from 0 to 1.6 MPa, No. 2 from 0 to 1.0 MPa;
- bypass valves - No. 1 up to 0.3 MPa, No. 2 up to 0.8 MPa.

2 Materials and methods

An experimental study of the "exhaust gas source - storage tank" system was carried out on an experimental stand for studying diesel engine exhaust gases (Figure 1). The experimental stand was developed and installed in the laboratory of the Department of Industrial Transport of the Abylkas Saginov Karaganda Technical University.

Conducting experiment No. 1 (1st mode - 900 rpm) on the experimental stand was carried out in the following order:

1) the protection of working personnel was checked for compliance with regulatory requirements and safety rules;
2) the laboratory premises were checked for compliance with regulatory requirements and safety rules;
3) the equipment of the experimental stand was checked for compliance with regulatory requirements and safety rules;
4) the signal to start experiment No. 1 was sent;

a) b)

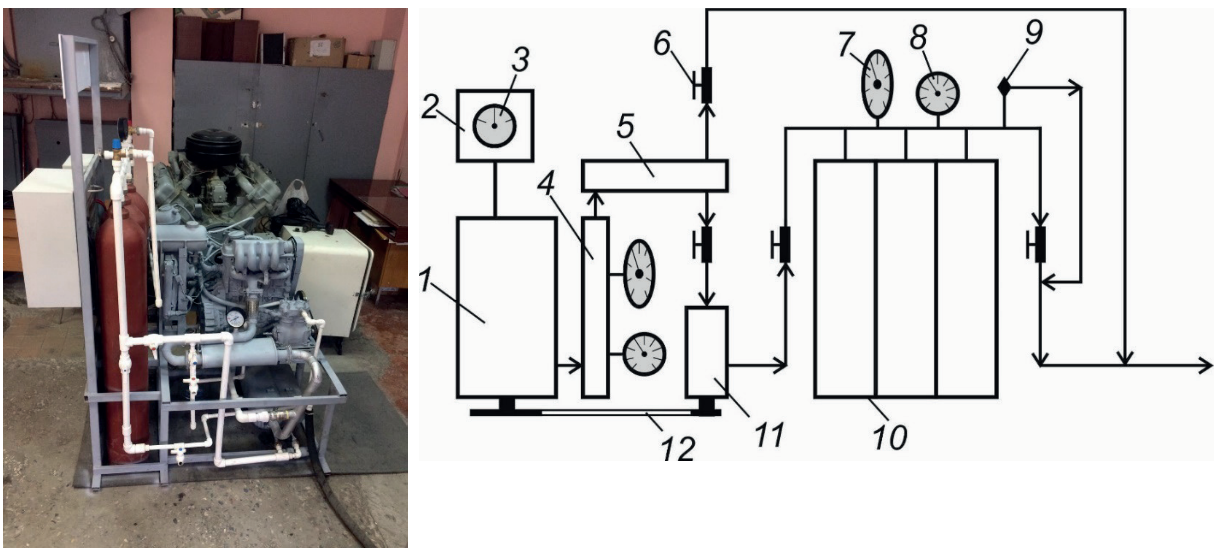

***Figure 1** Experimental stand for studying the system "source of exhaust gases - storage tank": 1 - ICE; 2 - ICE launcher remote control; 3 - tachometer; 4 - exhaust system; 5 - exhaust gas cooling tank; 6 - valve; 7 - thermometer; 8 - manometer; 9 - bypass valve; 10 - storage tank (consisting of 3 tanks); 11 - compressor; 12 - connecting gear*

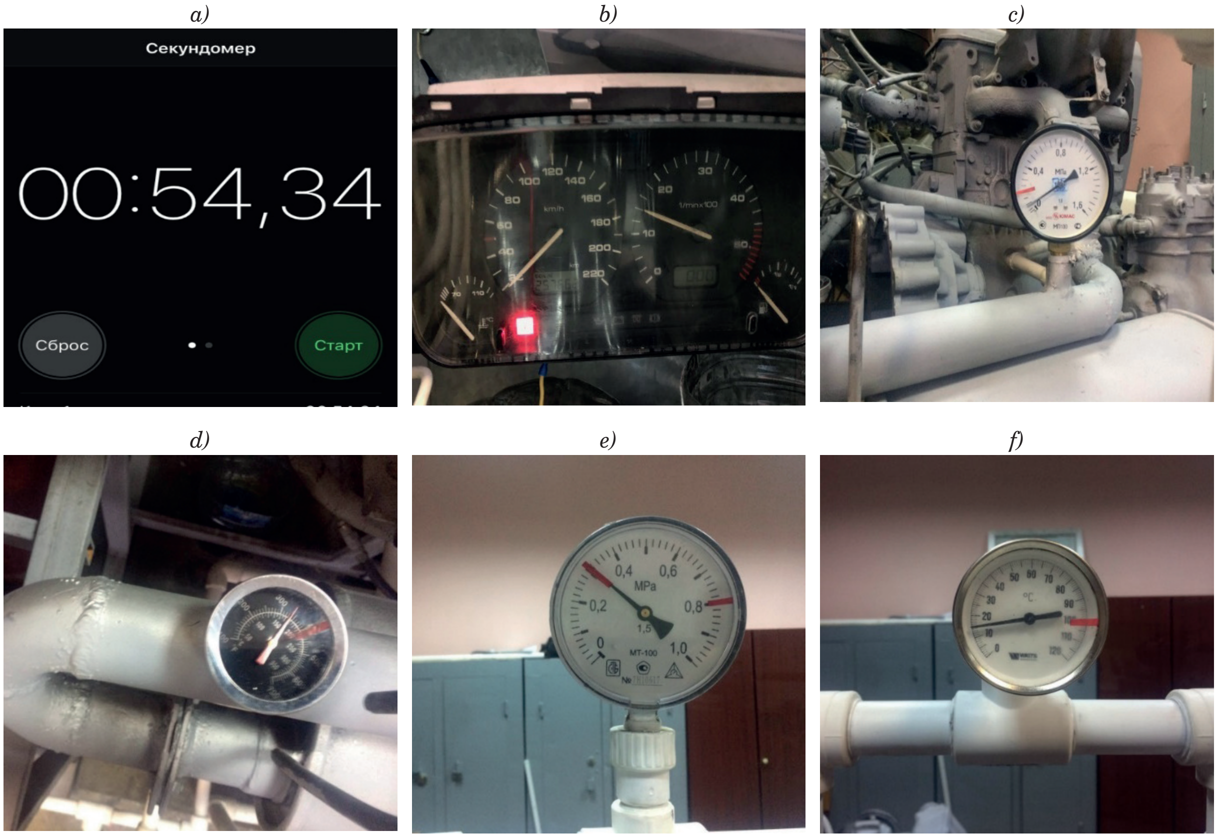

Figure 2 *Registration of the experiment No. 1 results: a - storage tank filling time; b - rotation frequency; c - exhaust pressure from the internal combustion engine; d - temperature at the outlet from the internal combustion engine; e - pressure in storage tank; f - temperature in the storage tank*

5) the internal combustion engine stand was launched;
6) the filling of the storage tank of the stand was registered and the results of experiment No. 1 were recorded:
   - ❑ time to fill the storage tank (Figure 2, *a*);
   - ❑ rotation frequency (Figure 2, *b*);
   - ❑ exhaust pressure from the internal combustion engine (Figure 2, *c*);
   - ❑ temperature at the outlet from the internal combustion engine (Figure 2, *d*);
   - ❑ pressure in the storage tank (Figure 2, *e*);
   - ❑ temperature in the storage tank (Figure 2, *f*);
7) the signal about the completion of experiment No. 1 was sent;
8) the internal combustion engine of the stand was stopped;
9) exhaust gas was discharged from the storage tank of the stand.

All the remaining experiments were carried out according to the above order for the selected loading modes of the internal combustion engine of the experimental stand:

- experiment No. 2 - 2nd mode - 1000 rpm;
- experiment No. 3 - 3rd mode - 1100 rpm;
- experiment No. 4 - 4th mode - 1200 rpm.

3 Results and discussion

The obtained results of an experimental study of the "exhaust gas source - storage tank" system based on 4 parallel experiments performed on an experimental stand (Figure 1) are presented in Figure 3.

Based on the analysis of the experimental curve of the average indicators for parallel experiments of the experiment (Figure 4 - *blue*), we select an empirical formula, after determining which one, we obtain its final form:

$$y_{Ti} = a \cdot e^{bx_i} = 490.4559 \cdot e^{-0.0024x_i}, \tag{1}$$

where x_i - rotation speed (influencing factor), n, m^{-1};
y_i - time to fill the storage tank of the experimental stand (output parameter), t, sec.

Substituting the average indicators for parallel experiments of the experiment (Figure 3), we obtained theoretical indicators, which are presented graphically in Figure 4 - *violet*:

$$\begin{aligned} y_{T1} &= 490.4559 \cdot e^{-0.0024 \cdot 55.7} = 56.3 \text{ sec}, \\ y_{T2} &= 490.4559 \cdot e^{-0.0024 \cdot 45.0} = 44.3 \text{ sec}, \\ y_{T3} &= 490.4559 \cdot e^{-0.0024 \cdot 33.5} = 34.8 \text{ sec}, \\ y_{T4} &= 490.4559 \cdot e^{-0.0024 \cdot 28.5} = 27.4 \text{ sec}. \end{aligned} \tag{2}$$

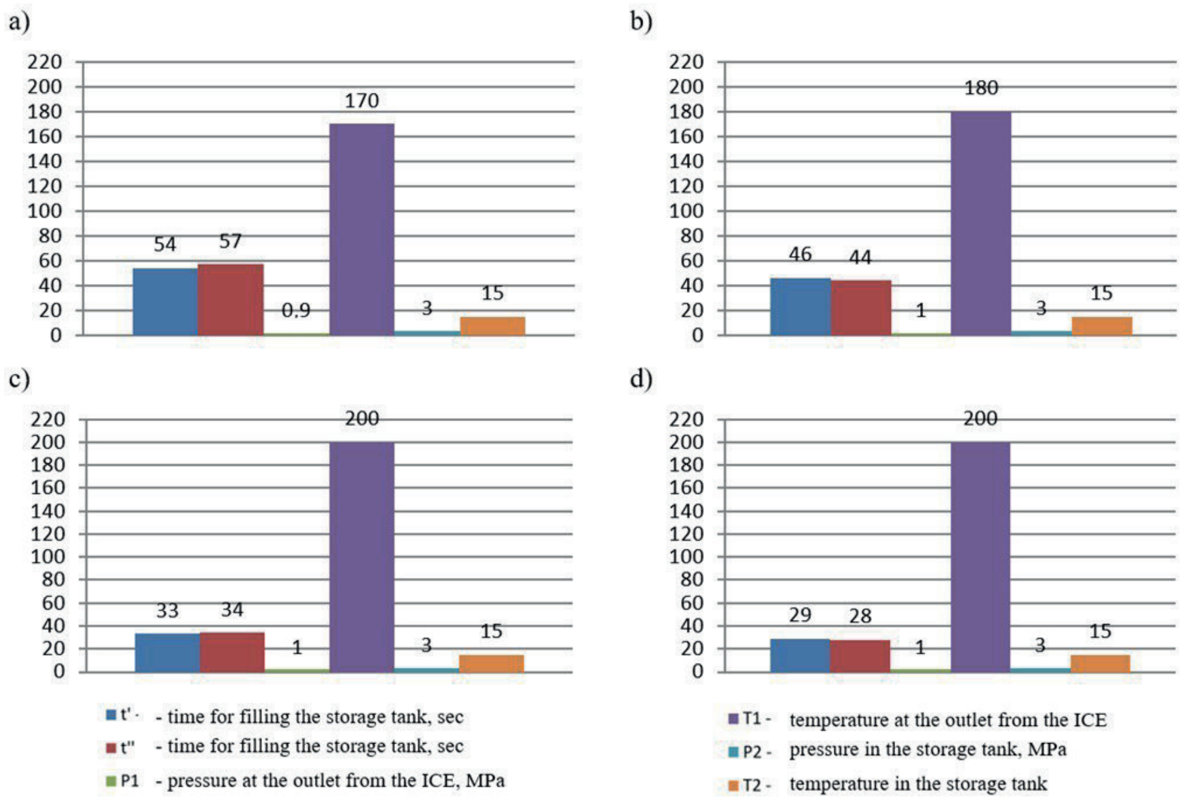

Figure 3 *Results of an experimental study of the "exhaust gas source - storage tank" system based on 4 parallel experiments: a - results of parallel experiment No. 1 at an internal combustion engine speed of 900 rpm (1st mode); b - results of parallel experiment No. 2 at an internal combustion engine speed of 1000 rpm (2nd mode); c - results of parallel experiment No. 3 at an internal combustion engine speed of 1100 rpm (3rd mode); d - results of parallel experiment No. 4 at an internal combustion engine speed of 1200 rpm (4th mode)*

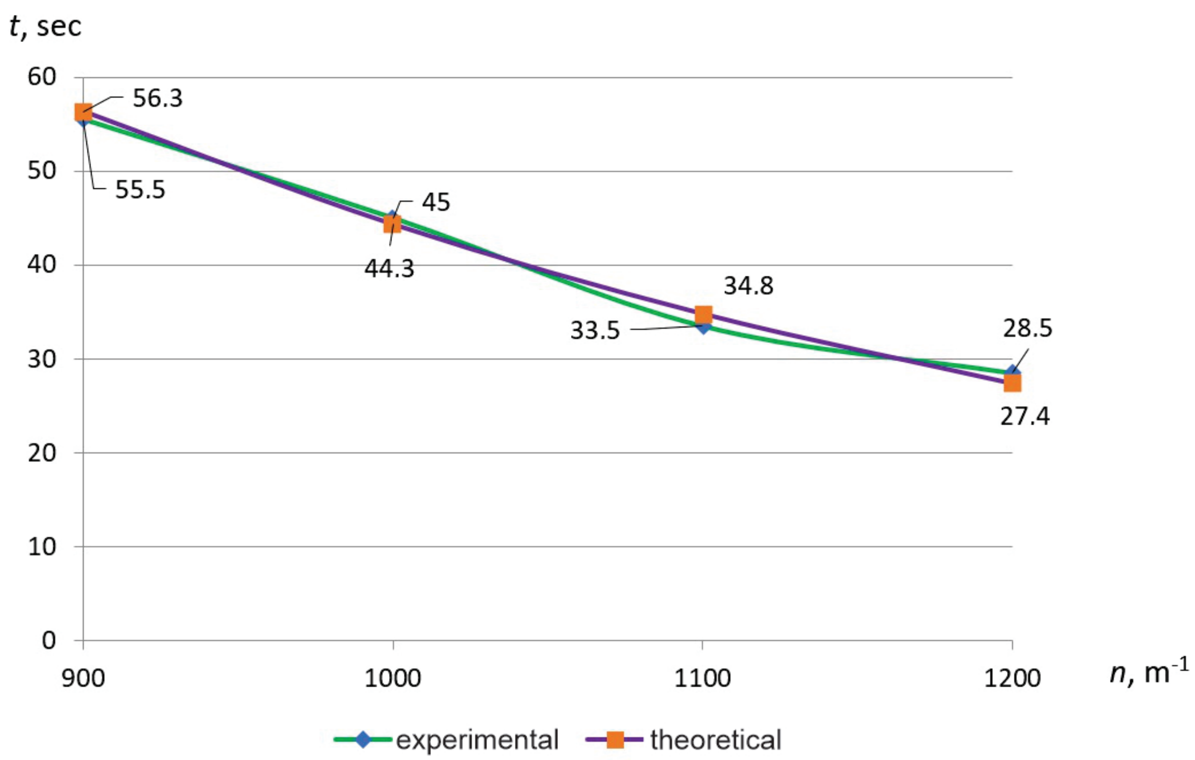

Figure 4 *Convergence of experimental and theoretical indicators*

To determine the percentage of scatter (variability) of the required function y_{Ti} (Equation (1)) relative to its average value, determined by the variability of factor x, the coefficient of determination was calculated [2]:

$$k_D = \left(\frac{N \cdot \sum x_i \cdot y_i - \sum x_i \cdot \sum y_i}{\sqrt{\begin{matrix} [N \cdot \sum x_i^2 - (\sum x_i)^2] \times \\ \times [N \cdot \sum y_i^2 - (\sum y_i)^2] \end{matrix}}} \right)^2$$

$$k_D = \left(\frac{4 \cdot 166000 - 4200 \cdot 162.5}{\sqrt{\begin{matrix} [4 \cdot 4460000 - 4200^2] \times \\ \times [4 \cdot 7039.8 - 162.5^2] \end{matrix}}} \right)^2 = -0.99^2 = 0.98. \quad (3)$$

The result obtained means that 98% of the spread is determined by the variability of x, and 2% by other reasons, i.e., the variability of function y (Equation (1)) is almost completely characterized by the spread of the factor x.

The suitability of the research hypothesis was assessed, as well as theoretical data for adequacy, i.e. correspondence of the theoretical curve (Figure 4 - *violet*) to experimental data (Figure 3). The essence of such a test is to determine the error of approximation of experimental data using the Fisher criterion, in which it is necessary to calculate the experimental value of the k_{FE} criterion and compare it with the theoretical ones - k_{FT}.

The experimental Fisher criterion is calculated using the well-known formula [2]:

$$k_{fe} = \frac{D_a}{D_{cr}} = \frac{\left(\sum_1^N (y_{iT} - \bar{y}_{ie})\right)^2 / (N - d)}{\left(\sum_1^m \sum_1^N (y_{iT} - y_{ie})^2\right) / (mN)}, \quad (4)$$

where D_a - adequacy dispersion;
D_{av} - average dispersion of the entire experiment;
y_{iT} - theoretical value of the function;
y_{iE} - experimental value;
$\bar{y}_{iE}$ - average experimental value from m measurements;
d - the number of coefficients in the theoretical regression equation; since in the theoretical expression there is one significant term x, then $d = 1$.

Substituting the data into Equation (4), we obtain the experimental Fisher criterion:

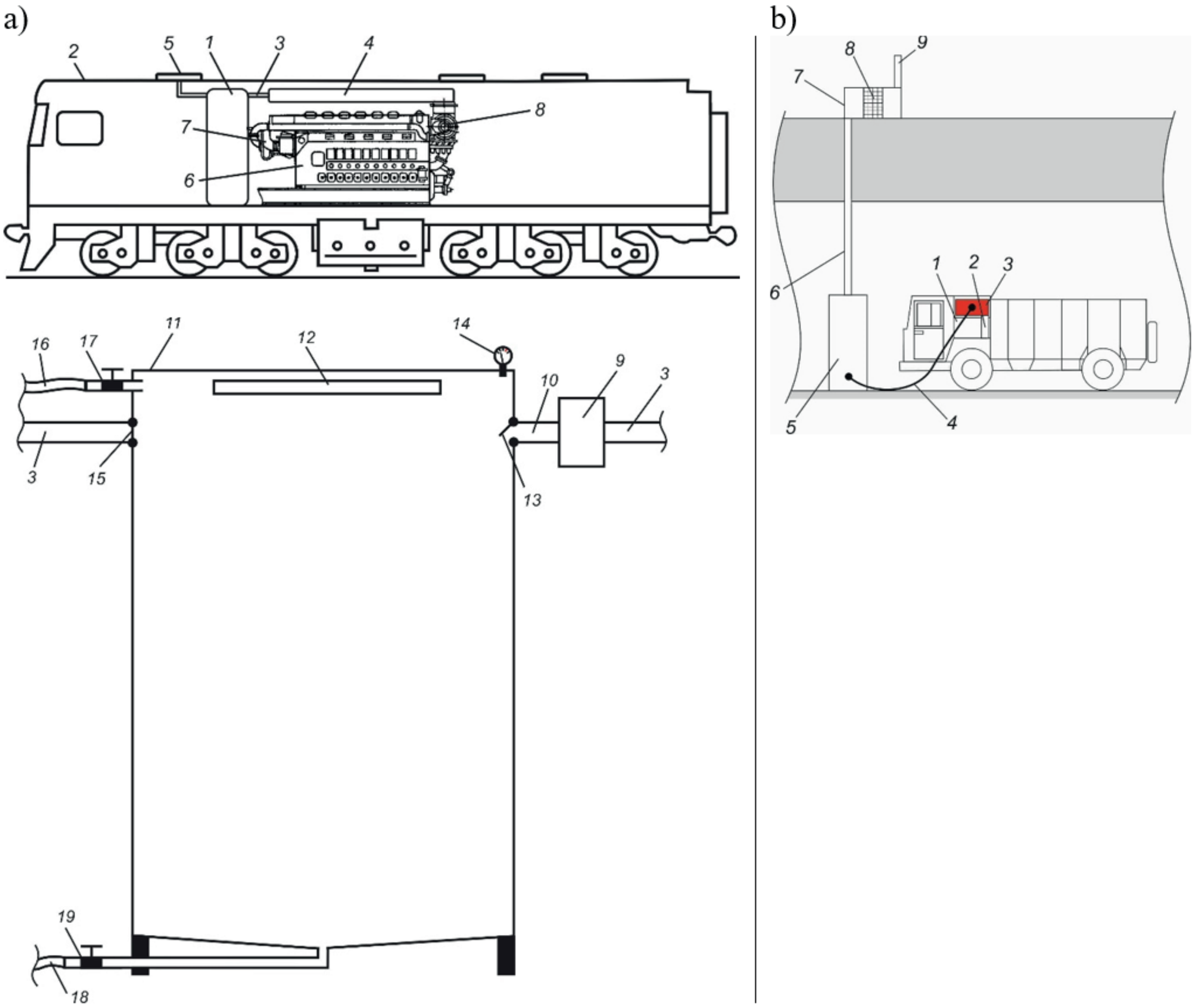

Figure 5 *Suggested practical application options: a) quarry diesel locomotive with proposed exhaust insulation device for diesel engine; b) underground self-propelled engine exhaust gas insulation device*

$$k_{fe} = \frac{0.8^2 + (-0.7)^2 + 1.3^2 + 1.1^2/4 - 1}{(23^2 + (-0.7)^2) + ((-1.7)^2 + (-0.7)^2) + + (1.8^2 + 0.8^2) + ((-1.6)^2 + (-0.6)^2)/ /2 \cdot 4} \tag{5}$$

$$k_{fe} = \frac{1.3}{1.95} = 0.7$$

The theoretical value of the Fisher criterion k_{FT} for a confidence probability of 0.95 and the number of degrees of freedom $q_1 = N - d = 4 - 1 = 3$, $q_2 = N \cdot (m - 1) = 4 \cdot (2 - 1) = 4$ is taken equal to k_{FT} = 9.1 [2]. Due to the fact that (k_{FE} = 0.7) < (k_{FT} = 9.1) - the model is adequate, i.e., the resulting mathematical model with a confidence probability of 95% describes well the process under study.

4 Conclusions

The problems of protecting the earth's atmosphere from the harmful effects of various types of transport are becoming increasingly urgent every year, their solution must be comprehensive and not a single source of exhaust gases that negatively affects the earth's atmosphere should be ignored [3-7].

An experimental study of the "exhaust gas source - storage tank" system, on an experimental stand developed for these purposes, confirmed the validity of the hypothesis about the possibility of isolating the exhaust gases from an internal combustion engine (exhaust gas source), by determining the time of filling the storage tank (experimental stand) with gases depending on the frequency engine rotation.

Based on the results of the research, the following were developed:

- a device for insulating the exhaust gases of a diesel locomotive engine (Figure 5, *a*), which contains the following equipment: proposed device 1, quarry diesel locomotive 2, connecting pipe 3, silencer 4, exhaust pipe 5; diesel engine 6, centrifugal supercharger 7, turbocharger 8, compressor 9, pipe 10, storage capacity 11, refrigerator 12, non-return valve 13, pressure gauge 14, bypass valve 15, discharge hose 16, valve nozzle 17, discharge hose 18, drain pipe with valve 19 [8-9];
- device for insulating the engine exhaust gases of an underground self-propelled machine (Figure 5, *b*), which contains the following equipment: engine of an underground self-propelled machine 1, compressor 2, storage capacity 3, exhaust hose 4, receiving tank 5, pipeline 6, purification tank 7, filter 8, exhaust system 9 [10].

However, the proposed method of isolating the exhaust gases of an internal combustion engine (source of exhaust gases), by filling the storage tank with gases using the forces of the exhaust gas source itself, is also applicable for other types of transport, and has promising applications.

The presented results of experimental studies, in our opinion, have serious applied significance, which will undoubtedly be of interest to engineers and scientists involved in research in the field of improving the environmental safety of vehicles.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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