DEVELOPMENT OF CALCULATION METHODOLOGY FOR OPTIMIZING THE OPERATING MODE OF AN ELECTRIC PULSE UNIT FOR CLEANING EXHAUST GASES

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Resume

The results of research, devoted to operation of an electric pulse muffler designed for cleaning exhaust gases of an internal combustion engine, are presented in this article. The problem considered in this research is establishing the optimal operating mode of the electric pulse muffler by changing the parameters of the distance between the electrodes and the frequency of the electric pulse. To solve this problem, experimental research on laboratory and experimental stands was carried out, which confirmed effective reduction of the gas smoke indices at adjustment of the specified parameters. As a result, a methodology was developed to calculate the optimal values of the distance and frequency parameters, at which the operation of the electric pulse muffler will be considered productive and the degree of gas purification will be effective. The optimum value of the distance between electrodes is 0.78-6 ·10-3 m with an electric pulse frequency in the range of 127-128·10^3Hz.

Available online: https://doi.org/10.26552/com.C.2024.011

Article info

Received 2 August 2023
Accepted 2 November 2023
Online 11 December 2023

Keywords:

internal combustion engine
exhaust gas, car muffler
electric pulse
frequency
distance between electrodes

ISSN 1335-4205 (print version)
ISSN 2585-7878 (online version)

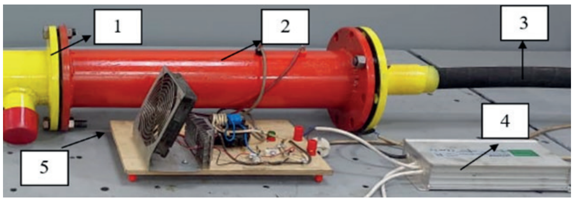
1 Introduction

To date, the steady increase in the number of motor vehicles worldwide leads to intense air pollution by exhaust gases. A high rate of air pollution was recorded in megacities, since most of the cars are concentrated on urban roads [1]. Air pollution is caused by the operation of automobile engines, which significantly worsens the urban ecological situation, which leads to deterioration of the overall quality of life of citizens through an increase in the number of various diseases, such as cardiovascular diseases, lung cancer and worsening metabolic syndrome [2-3].

The problem of emissions of harmful components of vehicle exhaust gases into the atmosphere in modern cars is solved by equipping the exhaust system with neutralizing catalysts, which are designed to neutralize harmful components of exhaust gas. In addition, the number of eco-friendly cars on the global automotive market is increasing, using the example of electric cars. However, in the coming years, it is impossible to replace all the cars with electric vehicles, since the electric vehicles on a single charge cannot ensure their long-term operation over long distances, and their charging at stations takes from 7 to 10 hours [4], at the same time catalysts are very expensive and have a short service life, every 100-120 thousand kilometres they need to be replaced [5].

In connection with the above, the search for new solutions for cleaning the exhaust gases of the internal combustion engine is relevant. One of such solutions is the application of electroimpulse method of purification in the exhaust system, as this method is characterized by a fairly fast rate of gas purification, and its purification efficiency is 98% [6].

A number of patents have been registered for cleaning the exhaust gases with an electric field and an electric pulse [7-8]. In the first case, purification is carried out due to the formation of a smoldering corona discharge, and in the second due to shock ionization of the gas. The disadvantage of these inventions is the need to introduce new structural units in the exhaust system,



1 - muffler housing; 2 - two electrodes mounted inside the housing; 3 - hose to the intake opening of the muffler; 4 - electric current source; 5 - high voltage generator

***Figure 1** Experimental electric pulse muffler*

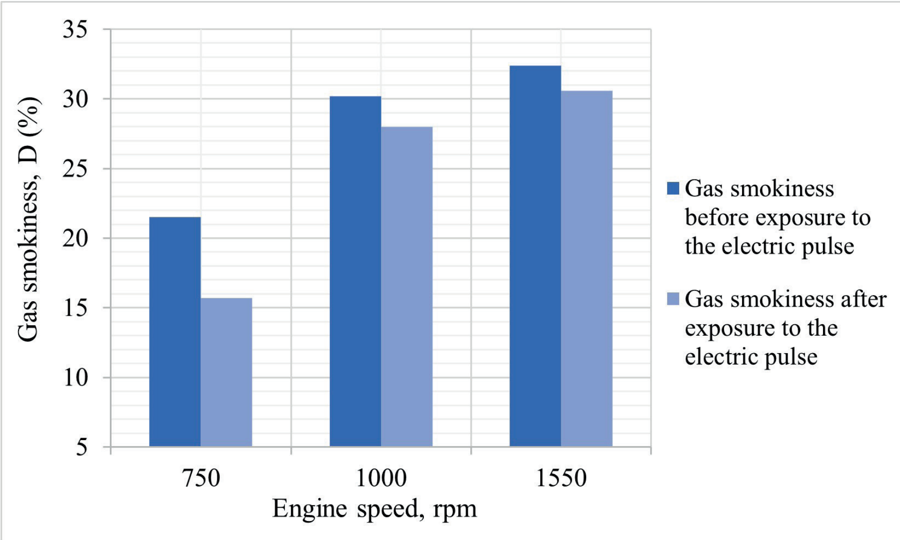


***Figure 2** Graph of the change in smokiness with and without the influence of an electric pulse*

which will weigh down the overall design and operation of the entire system.

We propose a new muffler design with placed electrodes inside the muffler, in which the shock ionization is carried out. The proposed design of the muffler does not weigh down the design of the exhaust system, as it is an alternative to the existing muffler, it does not have a significant load on the engine operation, as well, as the unit itself does not consume much power, and its development does not require large monetary costs. In addition, this muffler design can be a piece of equipment, not only in modern cars, but in the cars of earlier years of production, which correspond to the former "Euro" standards, as well.

However, when conducting theoretical and experimental researches of such a muffler, questions arise about obtaining the correct dependencies between parameters describing the muffler operation mode and the degree of gas purification. Consequently, it is necessary to develop a calculation methodology, determining the optimal values of parameters that allow to establish the operating mode of the electric pulse unit for exhaust gas purification.

The hypothesis of the study is the possibility of changing the gas purification mode and reducing its smokiness due to varying the distance between the electrodes and the frequency of the electric pulse.

The aim of the study was to establish the dependencies between the degree of gas purification, pulse frequency and the distance between the electrodes.

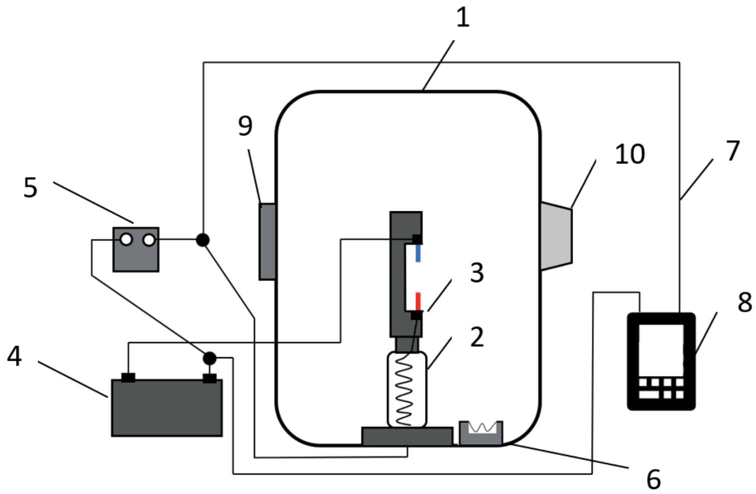
The scientific significance of the study is the establishment of dependences between the smoke content of the gas and the ratio of parameters pulse frequency and distance between the electrodes. The ratio of the indicators of the gas smokiness with and without the pulse treatment is taken as the criterion of purification.

The practical usefulness consists in obtaining correct dependencies for development of calculation methods for determining the optimum operating mode of the electric pulse muffler.

2 Materials and methods

The authors conducted an experiment that proved the effectiveness of the design with electrodes built into the muffler [9]. Figure 1 shows the experimental stand of an electric pulse muffler.

According to the experimental studies carried out on an experimental metal muffler stand the dependences of the gas smokiness indicators (after the impact and before the impact of the electric pulse) on the engine crankshaft speed were obtained (Figure 2).



1 - smoke storage tank; 2 - high-voltage ignition coil; 3 - spark plug; 4 - battery; 5 - frequency and duty cycle regulator; 6 - smoke source; 7 - connecting wires; 8 - luxmeter; 9 - light source

Figure 3 *Diagram of the experimental stand*

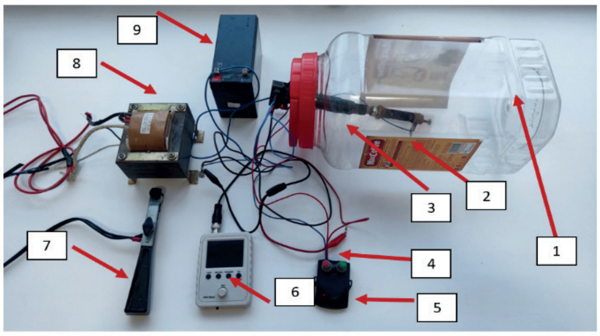


Figure 4 *Laboratory stand for determining the degree of gas purification*

The obtained results have generally shown the success of the experiment. From the graph it follows that the smokiness of the gas after exposure to an electric pulse has the lower values compared to the indicators of the smokiness of the gas that was not exposed to the electric pulse. However, in this experimental studies, in addition to the engine crankshaft speed, such important parameters as the distance between the electrodes and the frequency of the electric pulse were not taken into account, which has a direct impact on the quality of occurrence and duration of the corona discharge in the gas, which ensure the efficiency of the gas purification. In addition, by adjusting these parameters, it is quite possible to set the optimal mode of operation of the electric pulse muffler. For example, by varying the distance between the electrodes, it is possible to determine the optimal interval of the interelectrode space at which a corona discharge occurs and a high degree of gas purification is carried out. In addition, by selecting the value of the electric pulse frequency, it is possible to prevent cases of the transition of a corona discharge into a spark discharge [10], which leads to a violation of the stable mode of operation of the electric pulse muffler. Therefore, it is advisable to conduct experimental studies to determine the parameters of the gas smokiness with a change in the distances between the electrodes and the frequency of the electric pulse.

To determine the regularity of changes in the gas smokiness parameters' dependence on the parameters of the distance between the electrodes and the frequency of the electric pulse, the authors developed a laboratory stand with transparent dielectric walls, in which the distance between the electrodes changed and the frequency of the electric pulse was set. The scheme of the stand is shown in Figure 3.

The stand (Figure 4) consists of a smoke storage tank 1, a spark plug 2, a high-voltage ignition coil 3, connecting wires 4, a frequency and duty cycle regulator 5, an oscilloscope 6, a smoke source 7, an electric pulse generator 8, and a battery 9. .

A coil with a spark plug (NGK Iridium BKR5EIX-11 automotive spark plug) was placed inside the container. Spark plug has electrodes on it that can change their distance. The tank was filled with smoke from 10w 40 engine oil heated to a high temperature. To power the high-voltage coil, an electric pulse generator was used,

Table 1 Results of calculations to determine the gas smoke indices

Experiment number	Distance between electrodes Δ, (m)	Frequency of the electric pulse f, (Hz)	Gas illumination -E		Transparency coefficient -α	Total light absorption capacity of the gas β (Gas smokiness D_2/D_1)
			Before filling with the gas E_{of}	After filling with the gas E_i		
1	Δ_1=0.012	f_1=15.906	23 600	976	0.04136	0.95864
2	Δ_1=0.012	f_2=20.790	23 260	983	0.04226	0.95774
3	Δ_1=0.012	f_3=21.795	23 730	1058	0.04458	0.95542
4	Δ_2=0.015	f_1=15.906	23 570	1410	0.05982	0.94018
5	Δ_2=0.015	f_2=20.811	24 160	985	0.04077	0.95923
6	Δ_2=0.015	f_3=21.997	23 446	931	0.03971	0.96029
7	Δ_3=0.018	f_1=15.889	24 510	1981	0.08082	0.91918
8	Δ_3=0.018	f_2=20.725	23 285	1114	0.04784	0.95216
9	Δ_3=0.018	f_3=21.997	23 670	1121	0.04736	0.95264
10	Δ_4=0.021	f_1=15.889	23 832	1831	0.07683	0.92317
11	Δ_4=0.021	f_2=20.790	22 370	1286	0.05749	0.94251
12	Δ_4=0.021	f_3=21.975	22 235	1630	0.07331	0.92669
13	Δ_5=0.024	f_1=15.839	22 730	7387	0.32499	0.67501
14	Δ_5=0.024	f_2=20.790	20 977	6705	0.31964	0.68036
15	Δ_5=0.024	f_3=21.975	20 840	8078	0.38762	0.61238

assembled based on the KR1006VI1 (NE555) chip, operating in pulse-width modulation mode with the ability to adjust the frequency (from 15 to 35 Hz) on an oscilloscope. The stand was powered by a 12-volt battery.

The change of gas illumination in the container was recorded using an LED flashlight (HOROZ BECKHAM-1 HL341L,1W, 7000-9000K) and a special illumination sensor (UNI-T UT383).

Experimental studies at the laboratory stand were carried out in two stages: stage 1 - without exposure of the gas to the electric pulse, stage 2 - with exposure of the gas to the electric pulse. In addition, at the preparatory stage, the initial illumination of the container was measured without injecting smoke into the container, which averaged from 20.000 to 24.000 lk. The device was filled with smoke until the measured illumination decreased from an average of 800 to 400 lx. The readings were taken within 60 minutes. Moreover, to improve the accuracy of the results, readings were taken at every 15-second interval.

Experimental studies at the stand were carried out as follows. In the capacity of the laboratory stand, smoke came from a smoke source, the spiral of which was initially heated to a certain temperature appropriate for the applied engine oil. Measurements were taken on the illumination of the tank after filling with smoke. Then, a high-voltage electric discharge from the battery was applied to the electrodes located opposite each other at (Δ1= 0.012 m) in the spark plug and the frequency values (at f = 15 Hz) were adjusted using a regulator with a visual display of these values on an oscilloscope. The process of the smoke purification was observed in the tank and during which measurements of illumination were recorded. The order of the experiment was repeated in the same way several times, with changing the distance between the electrodes (at Δ_2 = 0.015, Δ_3 = 0.018 m, Δ_4 = 0.021 and Δ5 = 0.024 m) and adjusting the frequency of the electric pulse (at f_2 = 20 Hz and f_3 = 21 Hz).

According to the developed methodology of experimental data processing, the gas transparency coefficient α was calculated from the obtained values of the illuminance index E:

$$\alpha = E_i / E_{of} \,. \tag{1}$$

Transparency coefficient in turn allows to estimate the efficiency of gas purification by the parameter of gas light absorption capacity β. The dependence between the transparency coefficient and the gas light absorption parameter is as follows:

$$\beta = 1 - \alpha \,. \tag{2}$$

It should be noted that the light absorption capacity of gas β is a normative parameter describing the smoke index of the gas and is characterized by the ratio of the intensity of the light flux entering the receiver of the smoke path to the initial intensity of the light flux. Such ratio of light flux intensity is equivalent to the ratio of smoke indices after the impact and before the impact of the electric pulse on the gas in themuffler . Consequently, the parameter of light-absorbing ability of gas β is equal to the very index of ratios of gas smoke

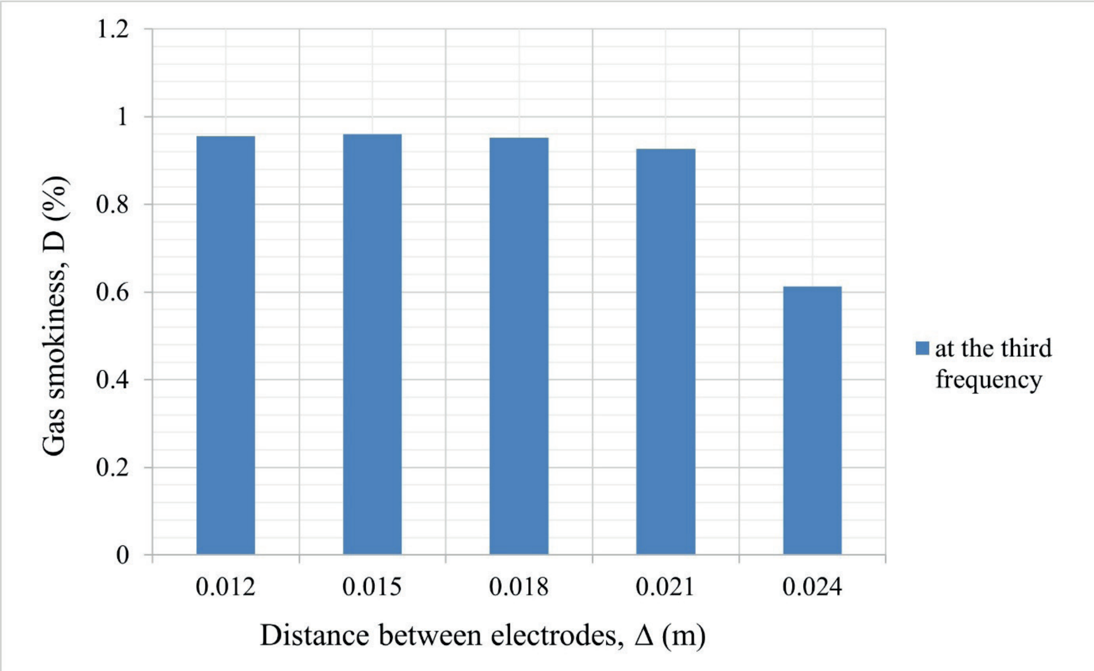


Figure 5 *Graph of the change in the gas smoke content depending on the distance between the electrodes*

after and before the impact of the electric pulse. Hence it follows:

$$\beta \approx D_2/D_1 . \quad (3)$$

It follows that, as a criterion for the optimality of the operation of an electric pulse muffler, it is advisable to choose the ratio of smoke indicators after (D_2) and before (D_1) the exhaust gas exposure to an electric pulse.

$$K_o = D_2/D_1 \rightarrow \min . \quad (4)$$

The results of calculations are presented in Table 1.

3 Results

According to the method of the experimental data processing, calculated values of the gas smokiness indicators were obtained, according to which, as a result, a graph of the dependence of the change in the gas smokiness on the distance between the electrodes and the pulse frequency was constructed (Figures 5 and 6, respectively).

From the graph in Figure 5 it follows that at a distance between the electrodes from 0.001 to 0.002 m, there was no qualitative change in the values of the smoke content of the gas. However, with an increase in the distance between the electrodes from 0.002 to 0.0024 m, the physical picture of the process of exposure to the electric pulse changed, in which there was a sharp jump towards a decrease in the values of the gas smokiness. This phenomenon can be explained by the fact that with the value of the distances between the electrodes from 0.012 to 0.0021 m, there was a spark discharge in the interelectrode gap and only with an increase in the distance between the electrodes to 0.0024 m, a spark discharge transition into a corona discharge occurred and gas purification became much more efficient. The degree of purification has increased by 40%.

From the graph in Figure 6 it follows that the frequency range of the electric pulse from 15 to 21 Hz was not significant in the process of gasses exposure to an electric pulse, since the smoke values remained almost unchanged. However, with an increase in the frequency of the electric pulse (more than 21 Hz), a gradual decrease in the gas smoke content was observed.

The obtained graphs prove that the distance between the electrodes and the frequency of the electric pulse have the greatest influence on the degree of gas purification. As a result, a graph was constructed for the joint analysis of the ratio of the gas smoke content dependence on parameters of the distance between the electrodes (Δ) and the frequency of the electric pulse (f) (Figure 7).

According to the obtained graph, it follows that with the combined effect of the frequency of the electric pulse and the distance between the electrodes on the gas, the smoke index begins to change approximately in the range of distances between the electrodes from 0.0018 to 0.0024 m. However, according to the results of the experimental data processing, it is not possible to determine the exact values of the electric pulse frequency dependence on the distance between the

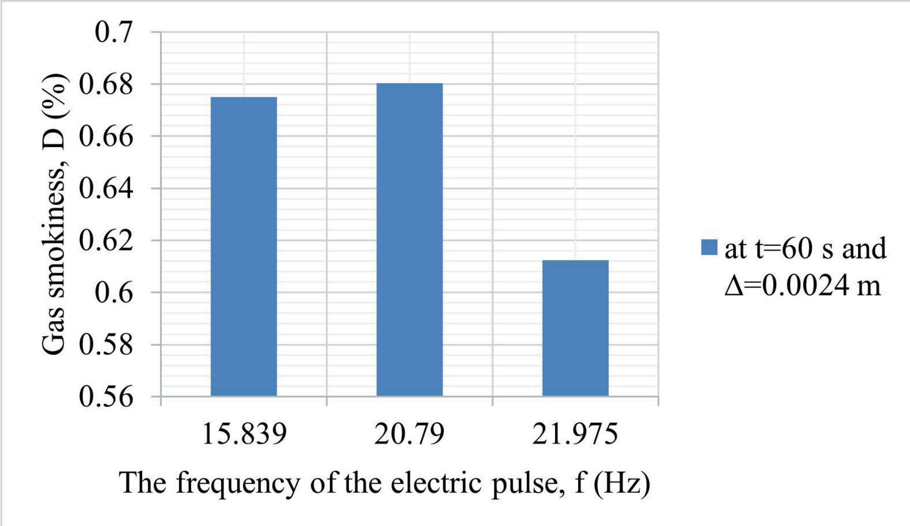


Figure 6 *Graph of the change in the smoke content of the gas depending on the frequency of the electric pulse*

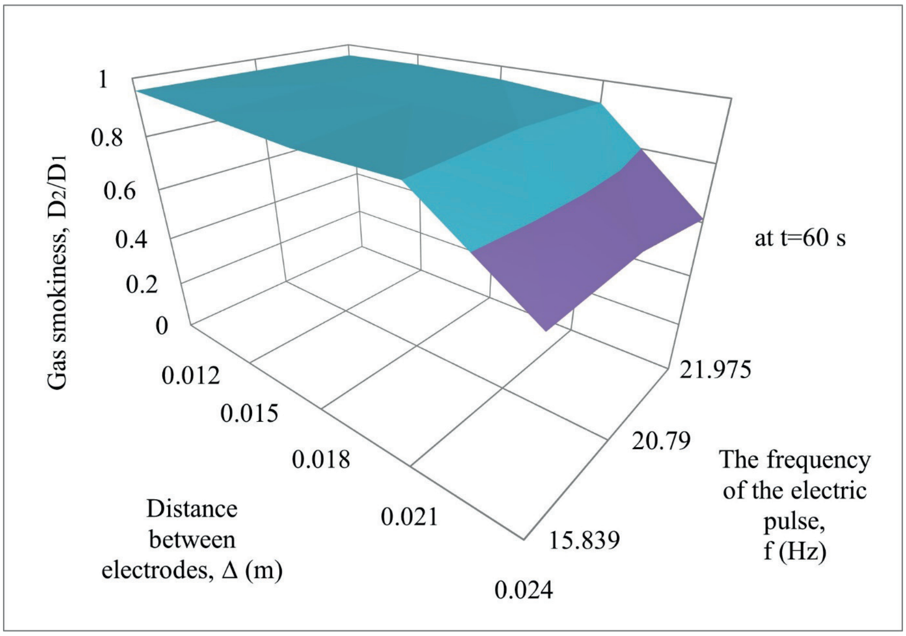


Figure 7 *The ratio of the gas smoke content dependence on the parameters of the distance between the electrodes (Δ) and the frequency of the electric pulse (f)*

electrodes, with the combined effect of which there is a decrease in the smokiness indicators. In this regard, it is necessary to establish dependencies that allow determining the relationship between the parameters of the frequency of the electric pulse and the distance between the electrodes.

To determine the joint effect of the parameters Δ and f on the smokiness of the gas, the authors considered two indicators:

$$k_1 = \Delta \cdot f \text{ and } k_2 = \Delta / f . \quad (5)$$

The physical meaning of the value k_1 is the speed ϑ_e of the passage of the distance S by the electric pulse. The value of S is equal to the product of Δ by the number of cycles n, that is:

$$S = \Delta \cdot n , \quad (6)$$

$$\vartheta = \Delta \cdot n/t , \quad (7)$$

where $f = n/t$.

The physical meaning of the value k_2, equal to

$$k_2 = \Delta \cdot t/n , \quad (8)$$

lies in time t/n for which the impulse overcomes the distance Δ .

According to the obtained dependencies, the values of the parameters $k_1 = \Delta \cdot f$ and $k_2 = \Delta / f$ were determined by multiplying and dividing the values of the distance between the electrodes and the electric pulse frequency, respectively. The results of the calculations are presented in Tables 2 and 3.

Then, according to the obtained values of the parameters k_1 and k_2, a regression-correlation analysis

***Table 2** Data for determining the parameter k_1*

Distance between electrodes Δ (m)	0.012	0.015	0.018	0.021	0.024
Frequency of electric pulse (Hz)			Parameter k_1, $\Delta \cdot f$ (m/s)		
15.839	0.190	0.237	0.285	0.332	0.380
20.79	0.249	0.311	0.374	0.436	0.498
21.795	0.261	0.326	0.392	0.457	0.523

***Table 3** Data for parameter definition k_2*

Distance between electrodes Δ (m)	0.012	0.015	0.018	0.021	0.024
Frequency of electric pulse (Hz)			Parameter k_2, Δ/f (m · s)		
15.839	0.00075	0.0009	0.00113	0.00132	0.001
20.79	0.00057	0.0007	0.0008	0.00101	0.00115
21.795	0.0005	0.0006	0.00082	0.00096	0.00110

***Table 4** Smoke indicators from k_1*

Parameter k_1, $\Delta \cdot f$ (m/s)	0.190	0.374	0.523
Gas smokiness, D_2/D_1 (experimental values)	0.95864	0.95216	0.61238
Gas smokiness, D_2/D_1 (according to the regression equation) $y = -6.75x^2 + 3.77x + 0.49$	+0.96270	0.95553	0.61512

***Table 5** Smoke indicators from k_2*

Parameter k_2, Δ/f (m · s)	0.0005	0.0008	0.001
Gas smokiness, D_2/D_1 (experimental values)	0.955	0.9521	0.675
Gas smokiness, D_2/D_1 (according to the regression equation) $y = -439120.28x^2 + 611.88x + 0.75$	0.036	0.03943	0.316

of the experimental values of smokiness was carried out. According to the results of analysis, it is proposed to use a quadratic regression equation to describe the dependence of the change in the parameters of the smokiness of the gas on the parameters k_1 and k_2,

For parameter k_1

$$y = -6.75 \cdot x^2 + 3.77 \cdot x + 0.49 . \tag{9}$$

For parameter k_2

$$y = -439120.28 \cdot x^2 + 611.88 \cdot x + 0.75 . \tag{10}$$

Experimental and empirical values of the gas smokiness indicators from the parameters k_1 and k_2 are given in Tables 4 and 5, respectively.

Based on the data obtained, graphs of the dependences of the parameters k_1 and k_2 on the smoke indicators are constructed (Figures 8 and 9, respectively).

As follows from the graphs (Figures 8 and 9), according to the minimum gas smoke values, the following system of two linear equations was made:

$$\begin{cases} \Delta \cdot f = 0.5 \\ \Delta / f = 0.0015 \end{cases} \tag{11}$$

and by solving this system of equations the optimum value of parameters of distance between electrodes and frequency of electric pulse for laboratory electric pulse installation was obtained: $\Delta \approx 0.027$ and $f \approx 19$.

Thus, the presented methodology allowed to establish the optimal mode of operation of the laboratory stand for the gas purification by determining the optimal values of the parameters of the distance between the electrodes and the frequency of the electric pulse at

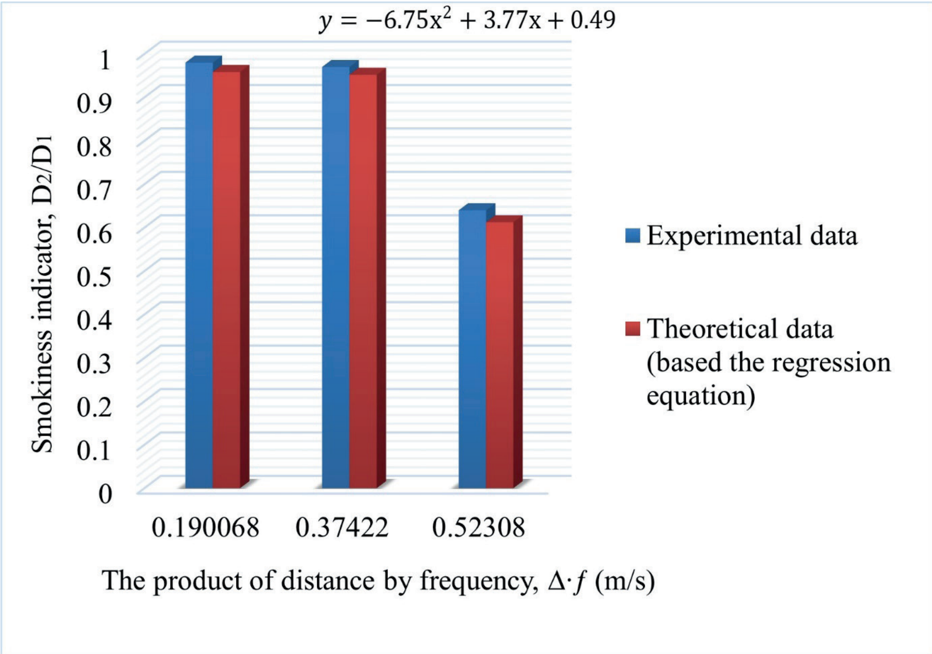


***Figure 8** Graph of the dependence of the comparison of experimental and theoretical curves for parameter k_1*

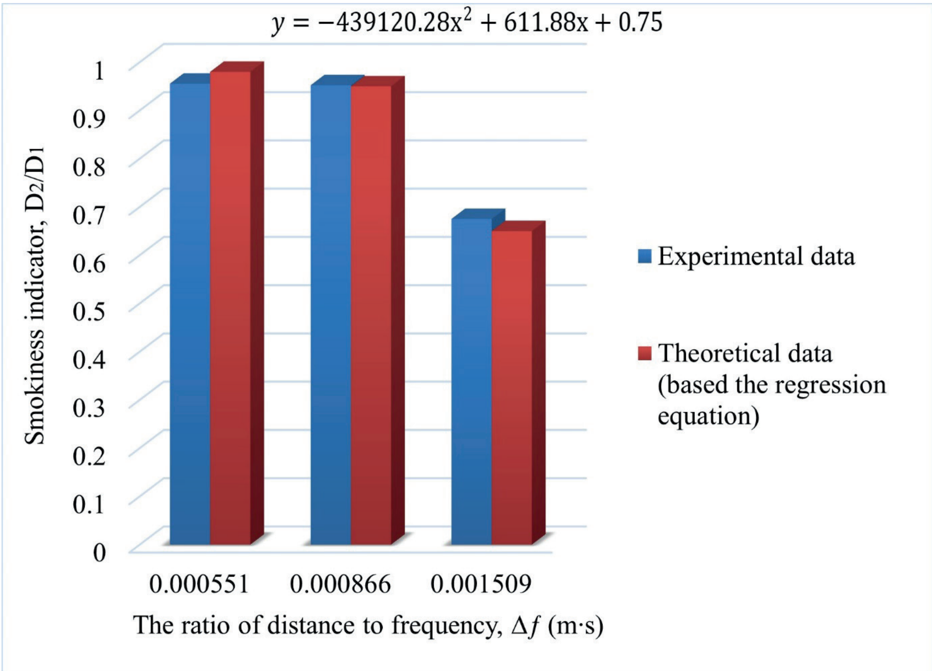
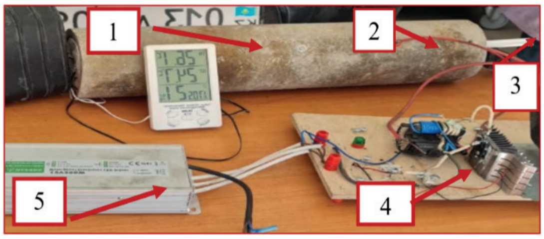


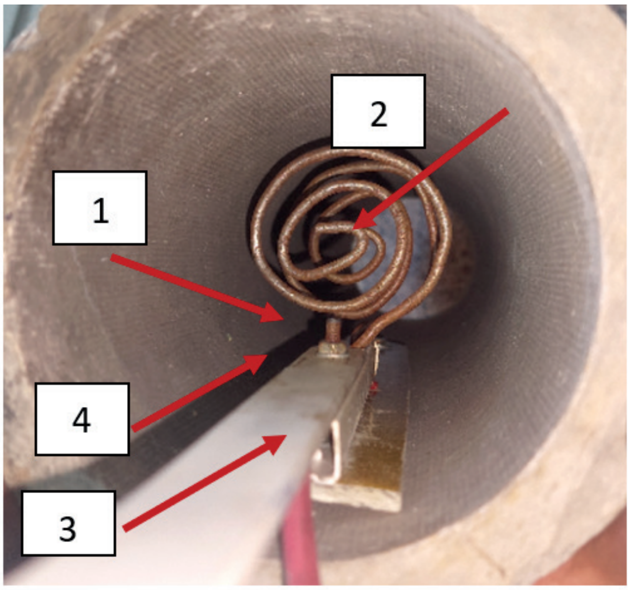
***Figure 9** Graph of the dependence of the comparison of experimental and theoretical curves for the parameter k_2*

which the lowest values of the gas smokiness indicators are achieved. However, the results obtained needed to be confirmed by experimental studies on an experimental stand of electric pulse muffler, since the influence of the engine crankshaft speed was not taken into account on the laboratory stand. After all, the engine crankshaft speed depends on how much gas is supplied to the electric pulse muffler. In addition, the establishment of optimal values of the parameters of the distance between the electrodes and frequency can prevent the transition of the corona discharge into the spark discharge, which is ineffective in the process of gas purification and has a destructive effect on the electrodes. In this regard, it is necessary to conduct additional experimental studies on the experimental stand to determine the indicators of gas smokiness dependence on the change in engine speed, taking into account the fixing of the electric pulse frequency indices and setting the distance between the electrodes, preventing the transition of corona discharge to spark discharge.



1 - asbestos muffler body; 2 - electrodes placed inside the muffler
3 - bar-rail for changing the distance between the electrodes;
4 - high voltage generator; 5 - power supply.

Figure 10 *Experimental stand of electric pulse muffler*



1 - anode; 2 - cathode; 3 - slat-rail for changing the distance between the electrodes;
4 - inner surface of the muffler housing

Figure 11 *Arrangement of spiral-shaped electrodes inside an electric pulse muffler*

Table 6 *Technical characteristics of the high voltage generator*

Indicators	Value
Input voltage	12 V
Output voltage	35000 V
Converter power	120 W

To determine the optimal mode of operation of an electric pulse muffler, depending on the change in the engine crankshaft speed, with the establishment of the optimal distance between the electrodes, the authors developed the experimental stand of an electric pulse muffler (Figure 10).

The cylindrical body of the muffler is made of asbestos, since this material has more positive characteristics compared to metal due to its low electrical conductivity, low thermal conductivity and high noise-absorbing ability. Inside the muffler housing, two electrodes are mounted on a special rail, to which a highvoltage electric current is supplied from the generator via the high-voltage wires (Figure 11).

The electrical circuit of a high-voltage generator consists of the following elements: a diode-cascade lowercase transformer (DCLT), a 1N5339BRLG zener diode, a TOSHIBA PNP 2SA1943 p-n-p transistor. The technical characteristics of the high voltage generator are presented in Table 6.

The experimental method consists of determining the parameters of the smokiness of the gas without exposure and with the influence of an electric pulse, depending on the change in the speed of the engine crankshaft with the establishment of optimal distances between the electrodes. The experiments were carried out in two stages: stage 1 - without affecting the gas with an electric pulse, stage 2 - with affecting the gas

Table 7 *Results of calculations of the ratio of the gas smokiness*

Engine crankshaft speed, (rpm)	750		950		1280	
Distance between the electrodes, (m)	0.01		0.078		0.06	
Frequency of the electric pulse, (Hz)	121 000		122 000		128 000	
Gas smokiness, (%)	Without the impact of an electric pulse (D_1)	With exposure electric pulse (D_2)	Without exposure to an electric pulse (D_1)	With exposure electric pulse (D_2)	Without the impact of an electric pulse (D_1)	With exposure electric pulse (D_2)
	50	45	40	34	39	29
	0.9		0.85		0.74	

with an electric pulse and setting the distances between the electrodes from 0.01 m to 0.006 m in increments of 0.02 m. The optimal distances between the electrodes for the experimental electric pulse muffler stand were selected based on the counter-proportional relationship between the parameters of the distance between the electrodes and the engine speed, which is described by the following equation:

$$\Delta = UqR^2/6Q\omega r\mu, \quad (12)$$

where:
U - voltage, V;
q - is the amount of charge, C;
R - is the radius of the muffler section, m;
ω - is the angular speed of rotation of the crankshaft, rad/s;
Q - capacity of the combustion chamber, m^3;
r - is the average radius of a gas particle, m;
μ - is the dynamic viscosity of the gas, Pa·s.

According to Equation (12), the greater the number of revolutions of the engine crankshaft, the smaller the distance between the electrodes should be. This is explained by the fact that at high frequencies of the crankshaft revolutions, the volume and velocity of the gas increase and this contributes to the fact that already at large distances between the electrodes, the process of electric pulse stitching of gases does not occur, namely, a corona discharge does not occur in the interelectrode space. Therefore, for a corona discharge to occur, it is necessary to reduce the distance between the electrodes. Consequently, for experimental studies, with an increase in the engine crankshaft speed, the distance between the electrodes was reduced.

Experimental studies on the experimental stand were carried out as follows. The car engine was started and warmed up to operating temperature. The experimental stand of an electric pulse muffler was connected to the car. A high voltage generator was connected to a muffler. The connection of the stand to the car was carried out through the inlet using a rubber hose feeding exhaust gases from the car. The engine crankshaft speed was set. The range of changes in the gas speed was 750, 950 and 1280 rpm. At each value of the engine crankshaft speed, the smoke content of the gas was measured using an optical smoke meter (BOSH BEA 070),. Then the same values of the engine crankshaft speed were set again and, depending on the change in their values, the gas smoke values were obtained, but with the influence of an electric pulse and with the distance between the electrodes (of 0.01, 0.0078, 0.006 m, respectively). Prior to exposure of the gas to an electric pulse, the distances between the electrodes were previously placed using a slat-rail. Then, an electric current was supplied from a high-voltage generator to the interelectrode space, during which a corona discharge was formed, followed by the beginning of the ionization process. The ionization of the gas led to the deposition of heavy particles on the inner surface of the muffler and the purified gas was released into the air through the outlet. The total exposure time of the electric pulse was 60 seconds, after which the smoke values of the gas were obtained.

Based on the conducted experimental studies on the obtained values of smokiness, their ratio was determined, namely, the ratio of the smokiness of a gas that was under the influence of an electric pulse to the smokiness of a gas that was not affected by an electric pulse. This ratio corresponds to the criterion of optimal operation of an electric pulse muffler, which characterizes the degree of gas purification, estimated by the degree of light absorption of the gas stream by suspended particles. The results of calculations of the ratio of smokiness of the gas are presented in Table 7.

According to the obtained calculated indicators of the gas smoke ratio, a graph of the dependence of their values on the engine crankshaft speed was compiled (Figure 12).

From the graph in Figure 12 it follows that the values of the gas smoke ratio tend to decrease as the engine crankshaft speed increases. For example, at 1250 rpm, the gas smoke values are 0.74 and the degree of purification has increased by 26%. Such indicators are explained by a decrease in the degree of light absorption of the gas by harmful particles and a subsequent increase in the degree of purification of the gas from harmful particles. A decrease in the smoke

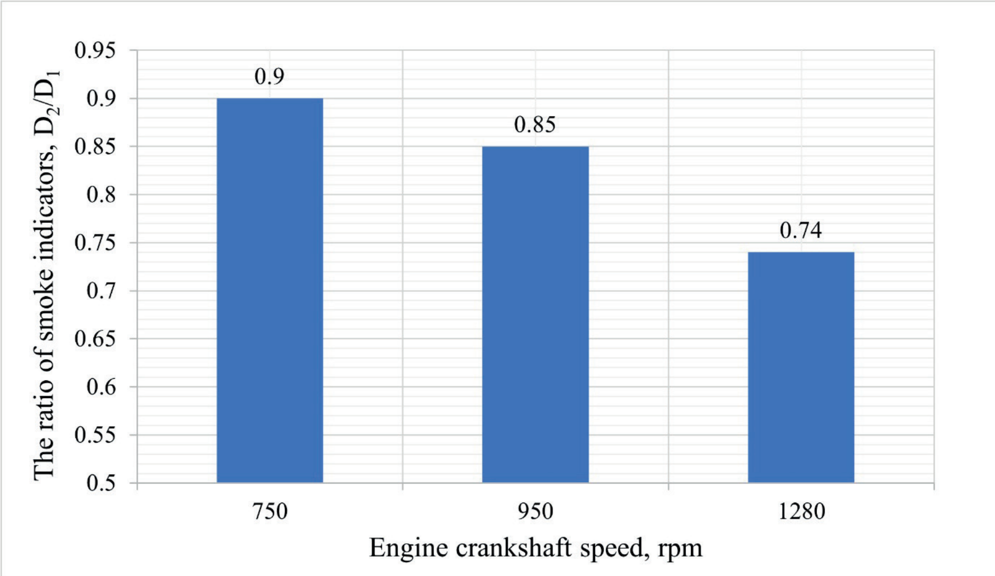


Figure 12 *Indicators of the gas smoke ratio depending on the change in the engine crankshaft speed*

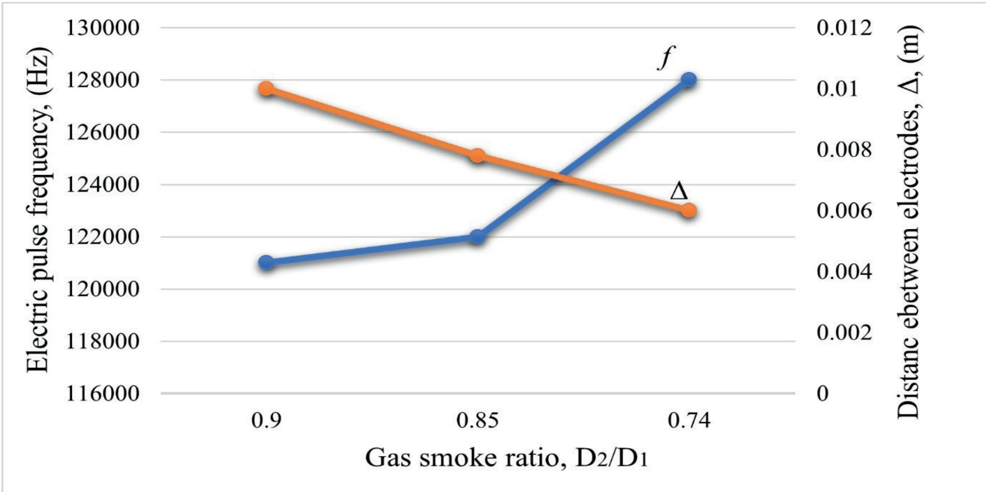


Figure 13 *Indicators of the gas smoke ratio depending on the change in the engine crankshaft speed and distance between the electrodes*

content of the gas, in turn, satisfies the condition of the optimality criterion, the value of which should tend to a minimum, which indicates an increase in the quality of gas purification and an increase in the efficiency of the electric pulse muffler.

Figure 13 shows the graph of change of the gas smoke ratio index dependence on the change of the electric pulse frequency and the distance between the electrodes.

According to the obtained graph it follows, the greater the influence of the frequency of the electric pulse, the lower the value of the gas smoke ratio. The lowest value of the gas smoke ratio was recorded in the area of the greatest influence of the electric pulse frequency of $128 \cdot 10^3$Hz, while the lowest value of the gas smoke ratio index was recorded at the smallest electrode spacing of 0.006 m.

The results obtained are explained as follows. As it was noticed earlier, for formation of the corona discharge it is necessary to vary the parameters of the distance between the electrodes and the frequency of the electric pulse. According to the conducted experimental studies on the laboratory and experimental stands, it follows that there is an inversely proportional relation between the distance and frequency, if the distance between the electrodes is large, then the frequency of the electric pulse will be small and vice versa, if the distance between the electrodes is small, then the frequency of the electric pulse will increase.

This inversely proportional relation is proved by the calculated results of the optimal parameters of distance and frequency, which were obtained according to methodology for the laboratory stand. For the experimental stands, the optimum values of the distance between the electrodes (Δ) and the frequency of the electric pulse (f) were also determined by using the previously presented methodology and they also confirm the existing relations between these parameters:

$$\Delta \approx 0.006\,\mathrm{m} \text{ and } f \approx 127 \cdot 10^3 \text{ Hz}. \quad (13)$$

Therefore, the distance between the electrodes of 0.006 m and the frequency of the electric pulse of $127 \cdot 10^3$ Hz are considered optimal for the formation of a corona discharge and subsequent effective gas purification in the experimental stand of a muffler.

4 Conclusions

According to the results of the conducted studies, the hypothesis about the possibility of changing the gas purification mode in the electric pulse muffler dependence on the change of the parameters of the distance between the electrodes and the frequency of the electric pulse was confirmed.

With the purpose of confirmation of the put forward hypothesis the laboratory and experimental stands were developed, allowing to carry out experimental research on definition of indicators of the gas smokiness dependence on parameters of distance and frequency.

Experimental studies on the laboratory stand allowed to determine that in the installation when the distance between the electrodes increases from 0.012 to 0.0021 m, there is a spark discharge in the inter-electrode gap, which is not effective for the gas purification, as the indicators of gas smokiness changed insignificantly. However, when the distance was 0.0024 m in the electrode gap there was a transition of spark discharge into corona discharge and gas purification became much more effective. It was established, that the increase in gas cleaning amounted to 40 %. Gas smoke indices were obtained according to the developed methodology of experimental processing. This calculation methodology allows to determine the coefficient of gas light-absorbing ability from the experimental values of gas illumination, which is equivalent to the gas smoke indices. The calculation methodology, which determines the optimal values of the parameters of the distance between the electrodes and the frequency of the electric pulse, and allows to establish the optimal mode of operation of the laboratory electric pulse installation, was also developed. Thus, at the frequency of the electric pulse of 19 Hz and the distance between the electrodes of 0.0027 m the operation of the laboratory electric pulse unit will be considered optimal.

The obtained research results needed to be confirmed on the experimental stand of the electric pulse muffler, taking into account the influence of the parameter of the engine crankshaft revolutions frequency and with establishment of the optimal distance between the electrodes. According to the results of the experiment the reduction of gas smoke indices was established, satisfying the condition of the optimality criterion of the electric pulse muffler operation, and the increase in the gas cleaning amounted to 26 %. In addition, the experimental results confirmed the opposite dependence between the parameters "distance and frequency". According to the previously proposed methodology, the values of the parameters of distance (0.006 m) and frequency ($127 \cdot 10^3$ Hz) were established for the electric pulse installation of the experimental stand, at which its operation and the process of gas purification would be considered optimal.

Thus, the obtained results allow to have scientific and practical significance for the development of calculation methodology for the design of electric pulse mufflers. In addition, the conducted research makes an important contribution to solving the problem of environmental pollution by cars and opens new perspectives for development of the electric pulse installations in the field of exhaust gas purification.

Grants and funding

The authors received no financial support for the research, authorship and/or publication of this article.

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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