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Application of electric pulse and ultrasonic mufflers for increasing the degree of exhaust gas purification in car engines

Adil Kadyrov[1], Bauyrzhan Sarsembekov[2*], Aliya Kukesheva[3], Kirill Sinelnikov[4]

[1,2,3,4]*Abylkas Saginov Karaganda Technical University NJSC, Kazakhstan.*

Corresponding author: Bauyrzhan Sarsembekov (*Email: baursk@mail.ru*)

Abstract

The purpose of the article is to compare the efficiency of using electro-pulse and ultrasonic mufflers for cleaning exhaust gases from internal combustion engines of automobiles. The authors have developed full-size stands for conducting experiments with both types of mufflers on gasoline and diesel engines. Experimental studies have shown that electro-pulse mufflers are more effective in reducing the smoke of diesel engine exhausts, while ultrasonic mufflers are promising for cleaning exhaust gases from solid particles of gasoline engines. In the electro-pulse muffler, at the considered values of the angular velocity of the engine, the smoke indicators of the gas decreased to approximately 30%, while in the ultrasonic one, to 15%. The changes in the mass of the sold particles in the ultrasonic muffler of a diesel engine and a comparison with a gasoline engine show that ultrasonic mufflers have a lot of potential to stop solid particles from forming in the gas flow. In particular, the mass of the precipitated particles in a gasoline engine is 3 times greater than in a diesel engine. The alternative mufflers studied in the article allow for the purification of exhaust gases from solid particles, reducing their negative impact on the environment and giving impetus to the development of environmentally friendly motor transport.

Keywords: Coagulation, Electric pulse, Gas cleaning system, Ionization, Muffler, Ultrasonic, Vehicle.

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1. Introduction

In the modern world, cars powered by internal combustion engines have become an integral part of human life, providing the opportunity to transport passengers and goods over long distances. Despite the positive aspects, cars running on gasoline and diesel fuel make their negative contribution to the environment [1].

The main problem is the emission of a significant amount of harmful substances into the environment through exhaust gases generated by the intensive use of fuel by vehicles. This problem is particularly acute in large cities and along highways, where they can contribute up to 80-90% of the polluting air. Moreover, vehicle emissions consist of over 200 toxic components, and these substances are released at a level that can be inhaled by humans, posing a significant risk to both environment and humans health [2-4].

The existing method of exhaust after treatment in internal combustion engines is not always reliable during vehicle operation due to the limited lifetime of catalytic converters [5, 6]. Alternatives such as natural gas, electric vehicles, and hydrogen engines have a number of disadvantages in the issue of urban infrastructure, travelling distances, economic efficiency of vehicles, and environmental issues of hydrogen and battery production [7, 8].

In the quest to reduce harmful emissions from vehicles, engineering solutions to improve the performance of the internal combustion engine's emission control system without significant design changes are becoming increasingly important. Utilizing advanced methods like electropulse and ultrasonic cleaning holds considerable promise as a strategy to enhance the effectiveness of exhaust gas purification. These methods can have a deeper impact on the smallest harmful gas particles, and under optimal conditions, the cleaning efficiency can reach up to 95-98% [9, 10].

To optimize the cleaning system of internal combustion engines, we propose the development of ultrasonic and electric pulse mufflers. The introduction of such mufflers will significantly improve the environmental performance of automobiles by making the cleaning process more efficient. However, for the practical implementation of this idea, further research and development are required, the results of which will allow us to conclude the feasibility of the application of electric pulse and ultrasonic mufflers and their settings for gasoline or diesel engines. The research's hypothesis and established the purpose of the research.

The research hypothesis is to assume the feasibility of using electric pulse mufflers for diesel engines and ultrasonic mufflers for gasoline engines. The physical properties of the electric impulse and ultrasonic cleaning have proposed such a hypothesis.

The purpose of the research is to experimentally determine the efficiency of the application of electric pulse and ultrasonic mufflers for internal combustion engines of automobiles. The practical significance of the conducted research lies in its potential to inform the design and application of electric pulse and ultrasonic mufflers in the exhaust gas purification system of car engines.

2. Materials and Methods

2.1. Exhaust Gas Cleaning Process with Electric Pulse and Ultrasound

A more thorough examination of the physical aspects of electric pulse and ultrasonic gas cleaning processes is essential for advancing the development of new muffler designs. Electric pulse cleaning relies on the ionization of gas molecules through electric discharge. The gas passes through an inhomogeneous electric field formed by two electrodes, to which a constant high voltage current is applied. When a sufficiently high voltage is applied across the interelectrode gap, an intensive shock ionization of the gas (compression of electric field lines) occurs near the surface of one electrode (corona electrode), followed by a corona discharge [11, 12].

As a result of the Corona discharge, gas ions of different polarities, such as positive ions, move to the Corona electrode and are neutralized, while negative ions and free electrons move to the precipitation electrode. When they contact the oncoming dispersed particles in the gas, they transfer their charge to them and attract them to the precipitation electrode. Consequently, the gas is purified, and its particles are deposited on this electrode [13, 14].

The fundamental nature of the ultrasound gas cleaning process involves the coagulation of solid particles in the flue gas, leading to their deposition as fouling at the device's bottom. Coagulation is understood as a physical and chemical process, adhesion and fusion of small solid gas particles with each other under the action of gravitational forces with their subsequent sedimentation. Between particles, there is a process of coagulation, but the process itself is very slow, and the ultrasonic field helps to increase the rate of coagulation of particles [15-21]. Figures 1 and 2 show the process of gas flow cleaning by electric pulse and ultrasound in the muffler.

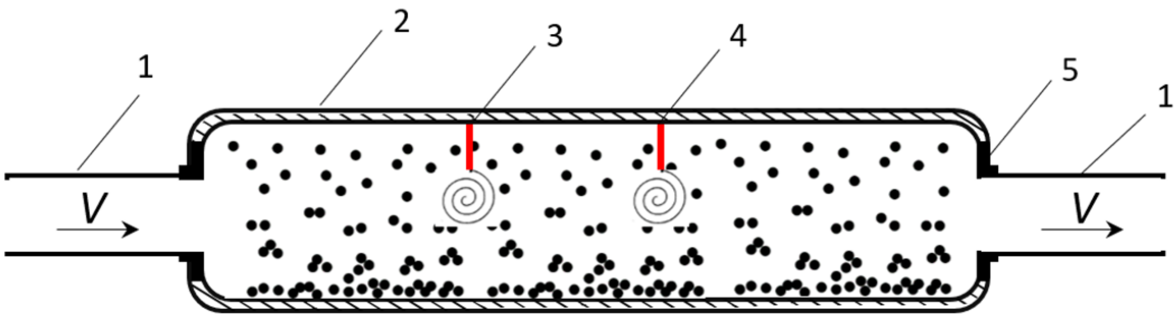


Figure 1.
The process of gas flow cleaning by electric pulse in the muffler.
Note: *1 - Exhaust system pipe; 2 - Muffler body; 3 and 4 - Electrodes; 5 - Connection with seal.*

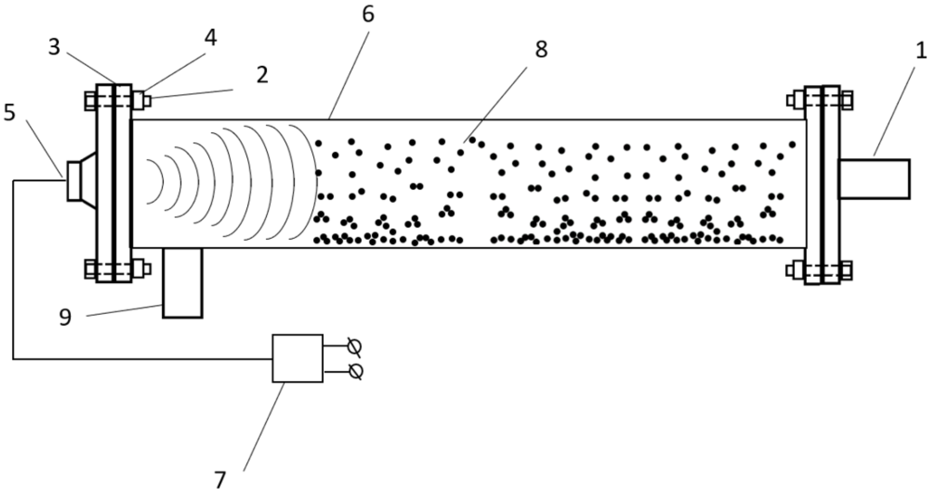


Figure 2.
The process of gas flow cleaning by ultrasound in the muffler.
Note: *1- Inlet pipe for exhaust gases, 2- Fastening bolt, 3- Flange, 4- Fastening nut, 5- Ultrasonic emitter, 6- Mounting structure (steel pipe), 7- Ultrasonic generator, 8- Zone of ultrasonic exposure, 9- Outlet pipe for exhaust gases.*

Upon analyzing the gas cleaning processes employing electric impulses and ultrasound, it was observed that these techniques effectively influence small gas particles, elevating cleaning efficiency through heightened ionization and coagulation, followed by deposition. Notably, the ionization process outpaces coagulation, as a rapid shock discharge between electrodes occurs, leading to a more efficient removal of harmful particles from the gas.

Despite the extended time required for gas purification, the ultrasonic method's coagulation process facilitates the formation of large agglomerates, resulting in an effective precipitation of particulate matter in the gas. Therefore, the mufflers of motor vehicles justify the use of ultrasonic and electrical pulse methods.

2.2. Design of Experimental Stands

To substantiate the practicality and efficacy of innovative muffler designs utilizing electric pulse and ultrasonic cleaning, it is imperative to carry out experimental investigations on specialized test benches.

The fundamental purpose of these experiments is to obtain metrics that validate the efficiency of applying electric impulse and ultrasonic mufflers in the internal combustion engines of automobiles.

For experimental research, full-scale test benches have been developed with electric pulse and ultrasonic mufflers (Figures 3 and 4).

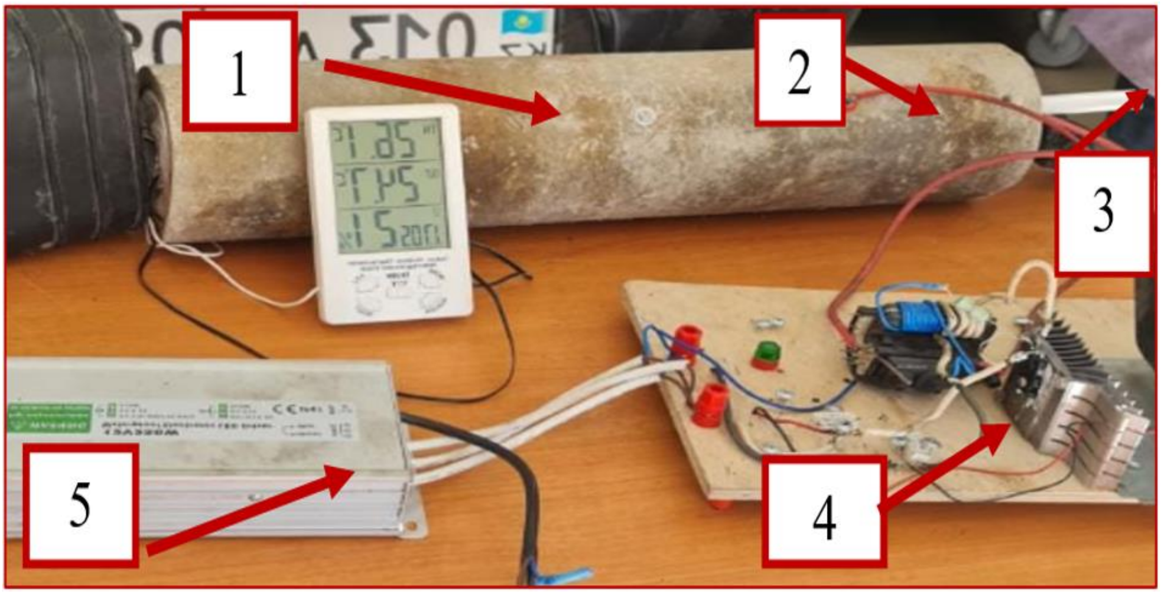
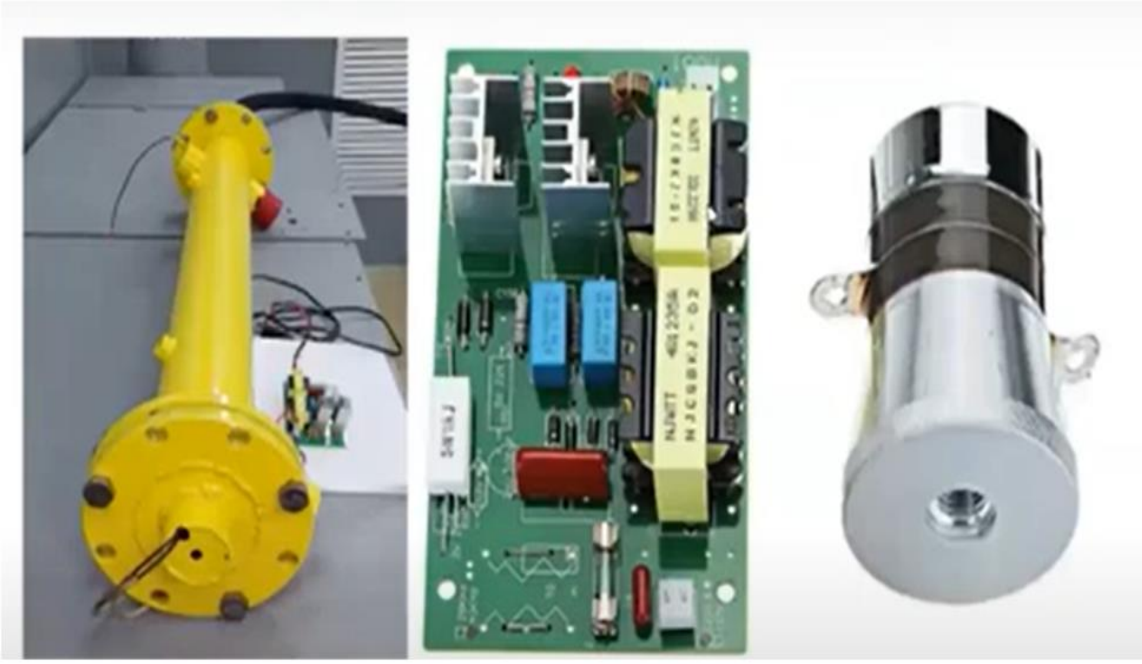


Figure 3.
Full-scale electric pulse muffler test bench.
Note: *1 - The muffler casing constructed from asbestos; 2 - Electrodes situated internally in the muffler; 3 - Track for modifying the spacing between electrodes; 4 - High voltage generator; 5 - Power supply.*



a) b) c)

Figure 4.
Full-scale ultrasonic muffler test bench.
Note: *a - Muffler bench, b) Ultrasonic generator, c) Ultrasonic emitter.*

We conducted experimental investigations on designated special benches, aiming to analyze the smoke indicators of exhaust gases emitted by a car's diesel engine. The focus was on examining how these indicators changed in relation to variations in the angular speed of the engine crankshaft.

The experiments also aimed to gather data on the mass of gas particles that settled at the bottom of the ultrasonic muffler-designed test match. Assessing gas smokiness and the mass of deposited solid particles provided a basis for estimating the extent of gas purification and drawing conclusions about the efficacy of the proposed mufflers.

Then the electric pulse or ultrasonic devices were connected to it as well. The housing of the muffler benches received the exhaust gases, and a gas analyzer measured the gas smoke values. The first stage of the experiment was the measurement of gas smoke levels without the influence of electric pulses or ultrasound. During the second stage, when the electric pulse or ultrasound was applied, the gas smoke indexes were measured again at each value of the angular speed of crankshaft rotation (79.5, 99.5, and 130.9 radians per second). The electric pulse and ultrasound were exposed for 60 seconds each.

There were also two stages of the particle mass experiments: the first one - without ultrasound exposure, and the second one - with ultrasound exposure at different values of angular velocity (99.5 and 130.9 rad/sec). We used five sheets of paper on a full-scale ultrasonic muffler to measure the mass of deposited particles. We weighed the paper both before and after the experiment. The effect of the ultrasound was evaluated at a fixed frequency of 40 kHz for a period of 5 minutes. An outlet hose vented the ultrasonically cleaned gas. The difference in paper mass before and after the experiment was used to determine the mass of deposited soot particles in the gas.

3. Results

3.1. Analysis of Experimental Results on Diesel Engine

The results of the experimental studies to confirm the feasibility and potential of using electric pulse and ultrasonic mufflers in vehicles are given in Tables 1 and 2.

Table 1.
Results of experimental studies determining the ratio of gas smoke indices in diesel pulse and ultrasonic mufflers.

Muffler type	**78.5 rad/s (750 rpm)**	**99.5 rad/s (950 rpm)**	**130.9 rad/s (1250 rpm)**
	Gas smoke indices ratio (D_2/D_1)		
Electric pulse	0.9	0.85	0.74
Ultrasonic	0.83	0.8	0.85

Table 2.
Results of mass change of deposited exhaust particles in diesel engine ultrasonic muffler.

Length of the deposited particles (m)	Mass of deposited particles (g) at (99.5 rad/s) Ultrasound exposure		Increase in mass of deposited particles	Mass of deposited particles (g) at (99.5 rad/s) Ultrasound exposure		Increase in mass of deposited particles
	Before	After		Before	After	
0.1	0.11	0.1	-0.09	0.32	0.87	0.2
0.2	0.06	0.14	1.33	0.41	0.93	1.26
0.3	0.12	0.21	0.75	0.53	0.94	0.77
0.4	0.23	0.32	0.39	0.64	0.98	0.53
0.5	0.15	0.28	0.86	0.7	0.69	-0.01
The sum of the increase in the mass of deposited particles			3.24	The sum of the increase in the mass of deposited particles		2.75

The obtained results led to the creation of a diagram showing changes in the ratio of gas smoke indicators in the electric pulse and ultrasonic mufflers of a diesel engine.

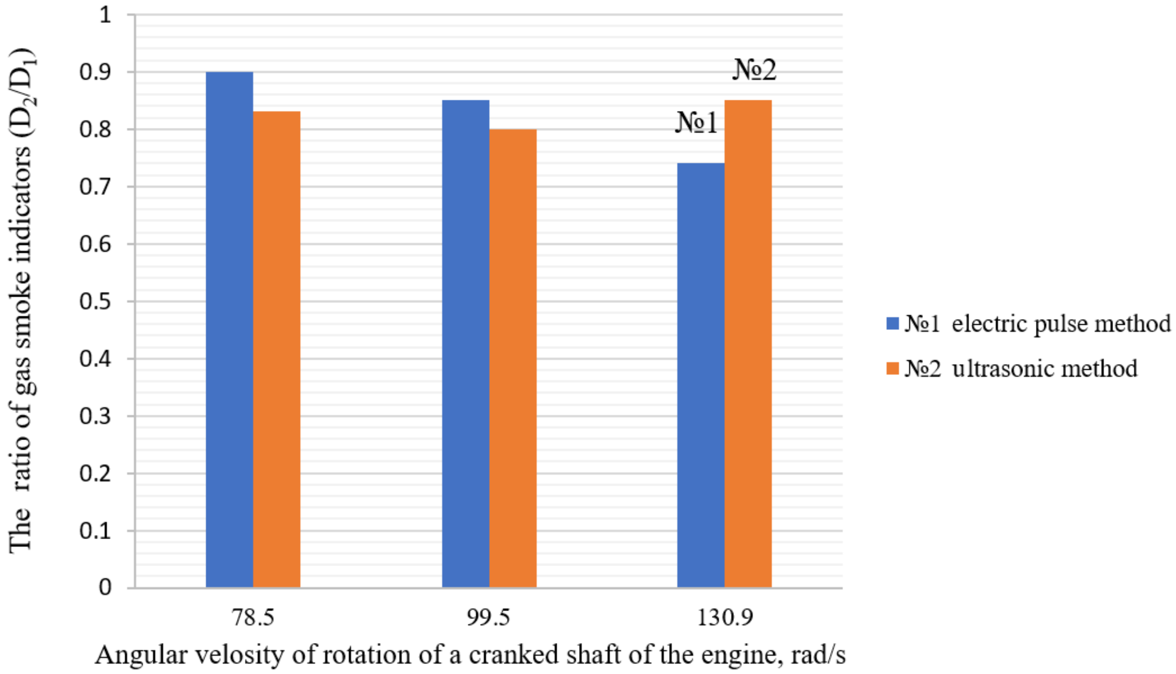


Figure 5.
Results of experimental studies on determining the ratio of gas smoke indicators in the electric pulse and ultrasonic mufflers of a diesel engine.

The graph (Figure 5) reveals a noticeable decline in the ratio of gas smoke indicators within the electric pulse muffler as the angular speed of the engine crankshaft increases. Notably, at an angular speed of 130.9 rad/sec, this ratio reached 0.74, showcasing a significant reduction compared to the corresponding value for the ultrasonic muffler. Specifically, with the electric pulse muffler, the gas smoke indicators decreased to about 30%, while with the ultrasonic muffler, it decreased to 15%. Therefore, the electric pulse muffler has a better performance in the purification of diesel engine exhaust gases than the ultrasonic muffler. The muffler's electrical equipment generates an electric field with an energy potential that determines the gas purification process. The electric field is capable not only of transferring energy to electrons and ionizing gas atoms or molecules, but also of subjecting them to the process of electrocoagulation along with the process of ionization. In turn, electrocoagulation aids in the thorough separation of gas particles from contaminants and expedites gas purification compared to ultrasound exposure.

3.2. Comparison of Experimental Results on Gasoline and Diesel Engines

Upon comparing the experimental findings concerning the mass of deposited particles in both diesel and gasoline engines, as outlined in B. Sarsembekov's thesis [15], it was evident that the ultrasonic muffler demonstrated suitability for application in gasoline engines. Table 3 presents the outcomes of tests that looked at how the mass of exhaust particles changed in mufflers made for both diesel and gasoline engines before and after being exposed to ultrasound.

Table 3.
Mass change of deposited exhaust particles in gasoline muffler.

Length of the deposited particles (m)	Mass of deposited particles (g) at (99.5 rad/s) Ultrasound exposure		Increase in mass of deposited particles	Mass of deposited particles (g) at (99.5 rad/s) Ultrasound exposure		Increase in mass of deposited particles
	Before	After		Before	After	
0.1	0.25	0.34	0.36	0.7	1.07	0.52
0.2	0.16	0.21	0.31	0.39	1.09	1.79
0.3	0.11	0.14	0.27	0.12	0.75	5.25
0.4	0.05	0.45	8	0.62	0.84	0.35
0.5	0.1	0.38	2.8	0.31	0.7	1.25
The sum of the increase in the mass of deposited particles			11.74	The sum of the increase in the mass of deposited particles		9.16

According to the obtained results of experimental studies, the corresponding diagrams showing the increase in mass of deposited particles after exposure to ultrasound in diesel and gasoline engines were made (Figures 6 and 7).

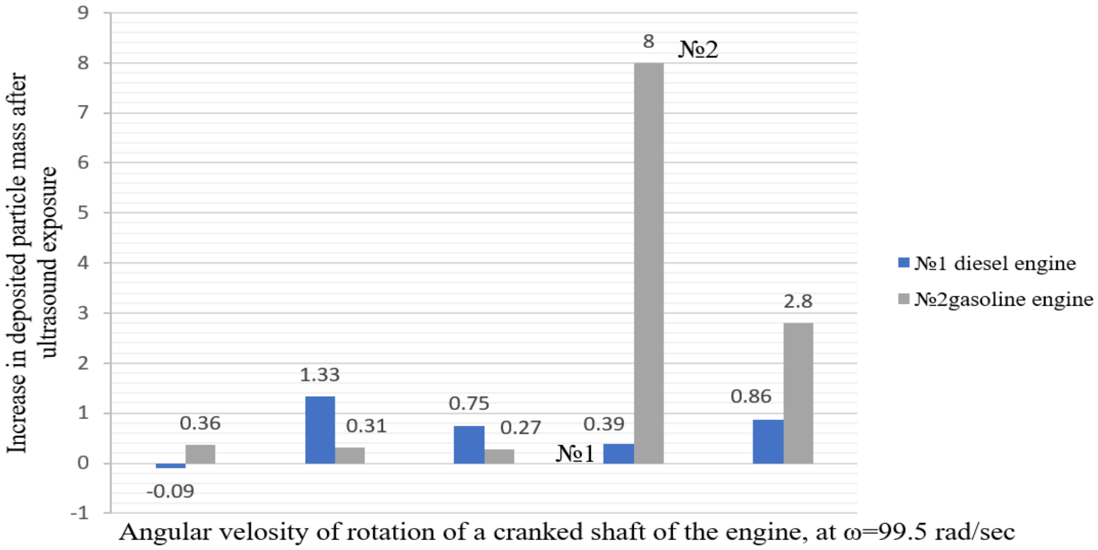


Figure 6.
Increase in deposited particle mass after ultrasound exposure in diesel and gasoline engines at ω=99.5 rad/sec.

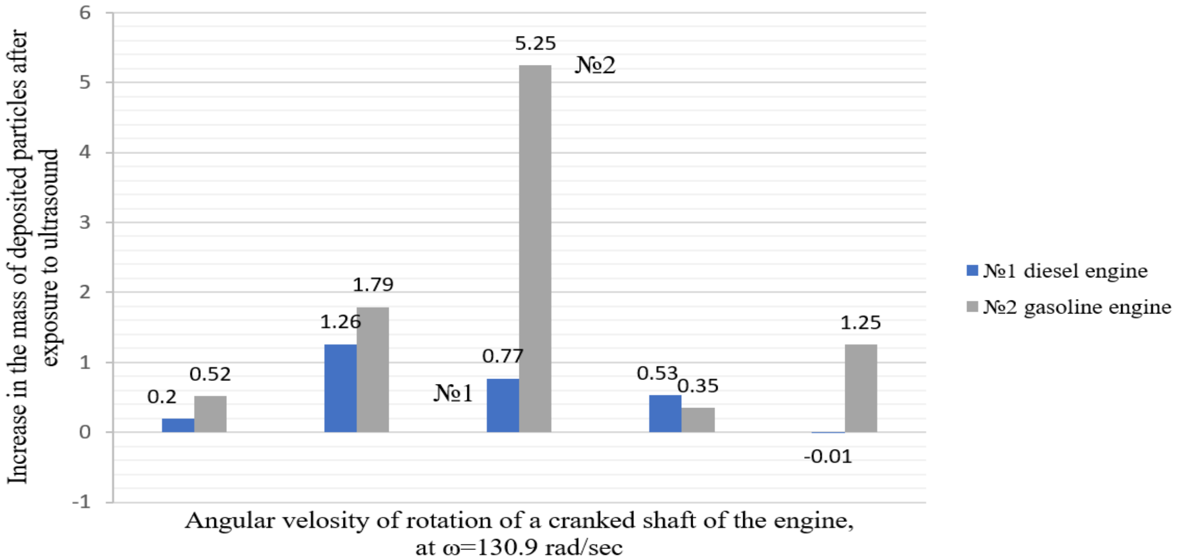


Figure 7.
Increase in the mass of deposited particles after exposure to ultrasound in diesel and gasoline engines at ω = 130.9 rad/sec.

Analysis of the obtained diagrams revealed a noticeable trend: at given values of the angular velocity of the engine crankshaft (99.5 rad/s and 130.9 rad/s), a more significant increase in the mass of deposited particles after gas ultrasonic exposure is observed in a gasoline engine compared to a diesel analogue. In particular, the sum of the mass of deposited particles in a gasoline engine is 3 times greater than that in a diesel engine. This discrepancy stems from the increased emission of carbon dioxide (CO_2) during the operation of a gasoline engine, resulting in a greater quantity of solid particles in the gas stream. The ultrasonic treatment proves more efficient in eliminating these particles from the gas stream in a gasoline engine than in a diesel engine.

The presented analysis of experimental results justifies the use of electric pulse and ultrasonic mufflers. For example, diesel engines generally have the potential for higher emissions of pollutants that can negatively impact the environment and human health. The increase in nitrogen oxide (NO_x) emissions is particularly noticeable in comparison to gasoline engines and is a contributor to smog and poor air quality.

However, diesel engines are highly fuel efficient, emit less carbon dioxide (CO_2) per kilometer, and are most efficient on long trips rather than in urban environments with constant stops and starts. Compared to diesel engines, gasoline engines require more revving due to their lower torque. Increasing engine speeds contributes to the release of more carbon monoxide and carbon dioxide into the atmosphere. Considering the characteristics of each type of engine, as well as the operating conditions of the vehicle, it is recommended to use electro-pulse mufflers for diesel engines and ultrasonic mufflers for gasoline engines. Such exhaust gas cleaning technologies help reduce harmful emissions into the atmosphere and improve the environmental friendliness of motor vehicles.

4. Conclusions

The experimental studies' results indicate the feasibility and prospects of using electro-pulse and ultrasonic automobile mufflers. The conducted studies confirm the effectiveness of each technology for cleaning the exhaust gases of internal combustion engines of cars.

Analysis of the results on the ratio of the indicators of exhaust gas smoke in electro-pulse and ultrasonic mufflers of a diesel engine allows us to conclude that the electro-pulse muffler is superior in reducing smoke. In the electro-pulse muffler, at the considered values of the angular velocity of the engine, the indicators of gas smoke decreased to approximately 30%, while in the ultrasonic one to 15%. This fact confirms the efficiency of the electro-pulse muffler.

The comparison between the mass of precipitated particles in the ultrasonic muffler of a gasoline engine and that of diesel engine highlights the potential benefits of using ultrasonic mufflers. In particular, the sum of the mass of precipitated particles in a gasoline engine is 3 times greater than in a diesel engine. Therefore, in gasoline engines, ultrasonic action is more effective, which makes such mufflers preferable for use with this type of fuel. The conducted research recommends the use of electric pulse mufflers for diesel cars and ultrasonic mufflers for gasoline cars, thereby optimizing the engine cleaning system's performance and minimizing the environmental impact. The proposed technologies promise not only to improve the environmental performance of cars, but also to increase their efficiency depending on operating conditions. Thus, research in this area provides an important contribution to the development of the transport industry, striving for a sustainable and environmentally friendly future.

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