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Environmental and Economic Feasibility of Implementing Electro-Impulse Mufflers on Motor Vehicles

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Abstract. The article addresses the issue of atmospheric pollution caused by motor vehicles and proposes a solution in the form of implementing electro-impulse mufflers for diesel engines. It presents the results of experimental studies confirming a reduction in CO_2 concentration and smoke levels, as well as an increase in oxygen content in exhaust gases. A methodology for calculating the economic efficiency of introducing electro-impulse mufflers has been developed, taking into account emission taxes and the prevention of environmental damage. Calculations specific to Kazakhstan show that the implementation of this technology leads to a 42% reduction in emissions, up to 25% fuel savings, a decrease in emission payments by 11 billion tenge annually, and the prevention of environmental damage amounting to over 1.25 trillion tenge. The results obtained demonstrate the environmental and economic feasibility of integrating electro-impulse mufflers into the national exhaust gas purification system.

Keywords: electro-impulse muffler, diesel engine, emissions, smoke level, economic effect, transport.

Introduction

Mechanical and automotive engineering play a key role in the modern economy by driving industrial development, creating jobs, advancing technological progress, and improving the population's standard of living. These industries contribute to increased mobility, enhanced efficiency in technical and logistical processes, and greater competitiveness of national production. However, the intensification of transportation flows, the growing number of motor vehicles, the expansion of urban agglomerations, and the rise in freight transport both within and outside cities are increasing the environmental burden on the natural environment. This is reflected in the rise of harmful emissions, air pollution, increased noise levels, and a decline in the quality of urban life. Therefore, the development and implementation of environmentally friendly and resource-efficient technologies in the transport sector have become particularly relevant.

One of the most significant negative consequences of the transport sector is the emission of exhaust gases, especially carbon dioxide (CO_2), which contributes to global warming and climate change. According to international studies, the transport sector is one of the largest sources of CO_2 emissions worldwide, with road transport accounting for 71.7% of these emissions. This highlights the urgent need for effective measures to reduce the carbon footprint [1, 2].

In addition, air pollution caused by nitrogen oxides, sulfur compounds, and soot particles has a serious impact on public health, provoking respiratory and cardiovascular diseases [3]. According to data from the World Health Organization (WHO), around 7 million people die prematurely each year due to the effects of air pollution (Figure 1).

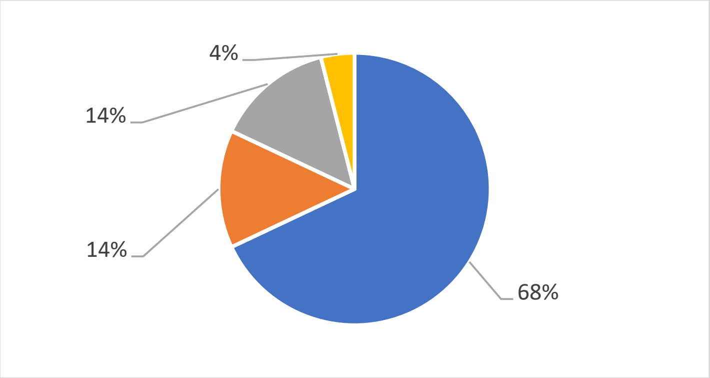


Fig. 1 – Indicators of the World Health Organization (WHO)

Approximately 68% of these cases are linked to ischemic heart disease and stroke, 14% to chronic obstructive pulmonary disease (COPD), 14% to acute lower respiratory infections, and 4% to lung cancer [4,5].

In Kazakhstan, air pollution is also a pressing issue. According to the World Bank's 2022 report, the country sees more than 10,000 premature deaths annually due to air pollution, resulting in economic losses of over 10.5 billion USD each year.

Several cities in Kazakhstan regularly experience concentrations of harmful substances in ambient air that exceed the maximum allowable limits (MAL). According to data from the Ministry of Ecology, Geology and Natural Resources, the most polluted cities include Astana, Almaty, Karaganda, Temirtau, and Aktobe (Table 1).

Table 1. The most polluted cities in Kazakhstan

№	City	Indicators
1	Astana	Over 1,300 cases of exceeding the MAL for harmful substances, especially near Babatayuly Street.
2	Almaty	1,940 cases of exceeding the MAL, particularly in the areas of the Almaty Arena Ice Palace and nearby residential districts.
3	Karaganda	56 cases of severe air pollution, mainly due to suspended particles (PM2.5 and PM10).
4	Temirtau	54 cases of high pollution, primarily from nitrogen dioxide.
5	Aktobe	Exceedances of the MAL for nitrogen dioxide and hydrogen sulfide were recorded [6,7].

Moreover, in dense urban traffic conditions, vehicles often operate at low engine speeds, are forced to stop frequently at traffic lights, idle in traffic jams, and move in a pattern of constant acceleration and braking. As a result:

– The level of harmful emissions increases, as fuel combustion becomes less efficient, leading to significantly higher emissions of nitrogen oxides (NO_x), carbon monoxide (CO), and particulate matter (PM2.5, PM10);

– The exhaust system operates sub-optimally, reducing the effectiveness of catalytic converters and diesel particulate filters (DPFs);

– Fuel consumption rises, adding further environmental impact and increasing operating costs;

– Engine lifespan decreases, as frequent stops and low-speed driving contribute to greater wear and tear of engine components.

To reduce the negative environmental impact of transportation under urban conditions, various technologies and methods are used worldwide. However, each has its own advantages and disadvantages.

One common solution is the use of electric and hybrid vehicles, which do not emit CO_2 or particulates during operation. However, widespread adoption is hindered by high costs, limited driving range, and insufficient charging infrastructure. Additionally, battery production requires rare earth metals, placing further strain on the environment and increasing dependence on finite natural resources. Mining and processing of rare earth elements are associated with significant environmental pollution, high energy consumption, and socio-economic risks - especially in countries where the major deposits are concentrated. Thus, despite their environmental benefits in operation, electric vehicles are not a fully “green” alternative and require a comprehensive life cycle impact assessment, from raw material extraction to battery disposal.

Another option is the use of biofuels, such as biodiesel and bioethanol, which can reduce carbon monoxide and particulate emissions. However, their use tends to increase nitrogen oxide emissions, and their production requires vast agricultural areas, often leading to deforestation and rising food crop prices.

To reduce emissions in diesel and gasoline vehicles, catalytic converters and diesel particulate filters (DPFs) are widely used. These effectively reduce harmful substances in exhaust gases but require regular maintenance and replacement. In city driving, where engines often run at low speeds, the effectiveness of these systems decreases, and their failure can result in costly repairs [8,9].

Another solution is the use of natural gas (compressed or liquefied). Gas-powered vehicles emit significantly fewer pollutants than traditional diesel or gasoline vehicles. However, modifications to the engine are required, and the lack of fueling infrastructure limits the widespread adoption of this technology [10,11].

A simple method for reducing emissions in urban driving is the implementation of start-stop systems, which automatically turn off the engine during stops at traffic lights or in traffic. This helps save fuel and reduce emissions, but frequent engine restarts increase the load on the starter and battery, potentially causing premature wear [12,13].

Based on the identified pros and cons of current methods and technologies, their practical implementation efficiency has been evaluated according to the following criteria: emission reduction effectiveness, economic feasibility, and implementation risks (Table 2).

Table 2. Evaluation of the Practical Effectiveness of Existing Emission Reduction Methods

Method	Emission Reduction Effectiveness	Economic Feasibility	Implementation Risks
Electric Vehicles	High (no emissions during operation)	Low (high purchase cost and infrastructure requirements)	High (underdeveloped infrastructure, expensive batteries)
Gas-powered Transport (CNG/LNG)	Medium (reduced NO_x and CO emissions)	Medium (costly equipment and fueling stations)	Medium (lack of refueling stations, vehicle conversion required)
Catalytic Converters and Diesel Filters	Medium (effective only at high temperatures)	Medium (high replacement and maintenance costs)	Medium (ineffective in urban conditions, risk of filter clogging)
Start-Stop System	Low (only saves fuel during idling)	High (simple and inexpensive to install)	Low (increased wear on battery and starter)

There are also domestic solutions aimed at neutralizing harmful emissions from vehicles. In particular, researchers from the Abylkas Saginov Karaganda Technical University, at the Department of “Transport Engineering and Logistics Systems,” are developing electro-impulse, ultrasonic, and laser mufflers for vehicles [14,15]. These devices are based on the physical principles of the impact of electro-impulses, ultrasound, and lasers on the exhaust gas flow, which leads to processes such as electrical ionization, ultrasonic coagulation, and laser dissociation — all of which contribute to reducing harmful substance content [16].

Preliminary experimental studies have already confirmed the effectiveness of the proposed methods, demonstrating a reduction in carbon dioxide levels, decreased smoke density, and increased oxygen concentration in exhaust gases [17,18]. However, the technologies are still in the testing phase and require further research to optimize their design and adapt them to various operating conditions.

Despite this, the proposed direction is considered promising because integrating electro-impulse, ultrasonic, and laser devices into vehicle exhaust systems does not require significant modifications to the exhaust system design, making it possible to implement them without substantial cost increases [19,20].

Electro-impulse mufflers are the most suitable for diesel engines since, compared to ultrasonic and laser mufflers, they offer stable influence on both smoke levels and gas composition. Additionally, electro-impulse mufflers have the following advantages:

First, electro-impulse technology maintains its effectiveness at low engine speeds, which is especially important for vehicles operating in conditions of frequent stops and acceleration in urban traffic. Unlike ultrasonic mufflers, which require a stable gas flow to effectively trigger coagulation processes, electro-impulse discharges act directly on soot particles and nitrogen oxides, breaking them down even during unstable engine operation.

Second, electro-impulse mufflers consume less energy than laser systems, making them a more economical and practical solution for vehicles where additional loads on the onboard power supply must be minimized. Laser systems require complex optical equipment and precise tuning to effectively decompose harmful substances, complicating their operation under conditions of high vibration and dustiness, which are typical for freight transport.

Moreover, electro-impulse mufflers can be easily integrated into standard exhaust gas systems without requiring significant structural changes. This allows for their use in both new vehicle models and as part of retrofitting already operating fleets, making them the most realistic and accessible solution for practical implementation.

Thus, electro-impulse mufflers represent the most optimal option for diesel engines, providing effective emission reduction, cost-efficiency, and reliability under demanding operating conditions.

However, the economic feasibility of large-scale implementation of electro-impulse mufflers has not yet been proven. Without proper economic justification, market introduction, commercialization, and the organization of mass production at machine-building plants could face difficulties. Therefore, the development of a calculation methodology proving the cost-effectiveness of implementing electro-impulse mufflers is a relevant task.

The objective of this study is to develop a methodology for calculating the effectiveness of implementing electro-impulse mufflers for diesel vehicles.

To achieve this objective, the following tasks were solved:

– the physical principles of electro-impulse muffler operation were examined;

– an analysis of experimental test bench results was conducted;

– a methodology for calculating the economic efficiency of electro-impulse muffler implementation was developed;

– the prospects for integrating electro-impulse mufflers into vehicle systems were assessed.

The scientific novelty of the research lies in obtaining new dependencies that confirm the effectiveness of the electro-impulse muffler implementation.

The practical significance of the research is as follows:
The results of the study can be applied in the modernization of exhaust gas treatment systems for diesel vehicles. This will help reduce air pollution, lower tax payments for harmful emissions, and improve the economic efficiency of logistics operations.

The developed calculation methodology can serve as a primary tool for assessing the potential of introducing electro-impulse mufflers into industrial production.

Thus, the study aims not only to scientifically justify the efficiency of electro-impulse mufflers but also to prove their economic and market feasibility, paving the way for mass production and commercial application.

1. Materials and Methods

The gas purification process in the electro-impulse muffler is based on the formation of a corona discharge between the electrodes [21]. A corona discharge is a glow that appears around the tips of electrodes when high voltage is applied, subsequently leading to the ionization process (Figure 2).

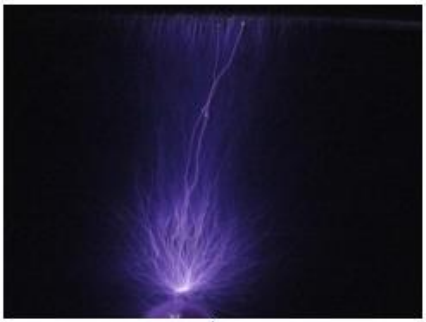
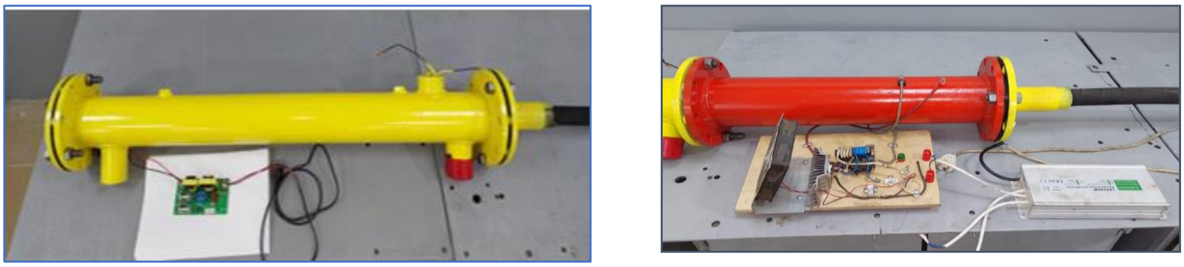


Fig. 2 – Corona discharge

Gas ionization is a process in which gas atoms or molecules lose or gain electrons under the influence of an electrical discharge. As a result of ionization, electrically charged particles are formed: positive ions if an atom loses an electron, and negative ions if it gains an electron [22].

The charged particles, while moving through the muffler, are attracted to the neutral gas particles, forming large aggregates that settle at the bottom of the housing due to electrocoagulation [23].

Experiments conducted on test benches with the electro-impulse muffler, and comparisons with the results from tests using ultrasonic and laser mufflers, confirmed the effectiveness of gas purification using electro-impulse technology (Figure 3).



a) ultrasonic muffler

b) electro-impulse muffler

c) laser muffler

Fig. 3 – Experimental test benches for electro-impulse, ultrasonic, and laser mufflers.

Changes in carbon dioxide (CO_2) and oxygen (O_2) concentrations at various engine speeds were used as evaluation indicators. The experimental results for CO_2 and O_2 levels obtained from the three muffler test benches are presented in Table 3.

Table 3. Results of experimental research

№	Engine speed, rpm	Before exposure	750-1000	1000-1400	1400-1550
	Impact		after	after	after
1	CO_2 (Electro-impulse)	2,38	2,35	2,27	2,1
2	O_2 (Electro-impulse)	17,18	17,27	17,46	17,66
3	CO_2 (Ultrasound)	2,26	2,25	2,23	2,18
4	O_2 (Ultrasound)	17,34	17,36	17,46	17,5
5	CO_2 (Laser)	1,4	1,35	1,35	1,38
6	O_2 (Laser)	18,97	18,87	19,01	18,43

Based on the experimental data presented in Table 3, comparative graphs were created to show the effectiveness of the three types of exhaust gas treatment (electro-impulse, ultrasonic, and laser) in terms of CO_2 and O_2 indicators for diesel engines (Figures 3 and 4).

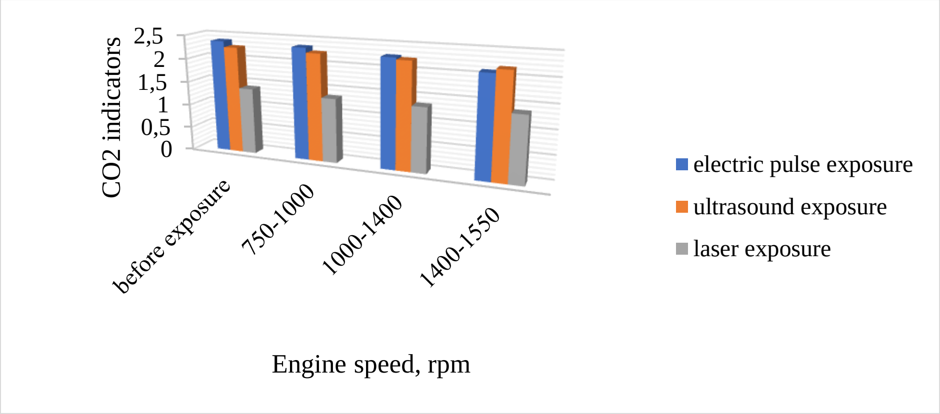


Fig. 3 – Comparison of the efficiency of three types of treatment on CO_2 indicators

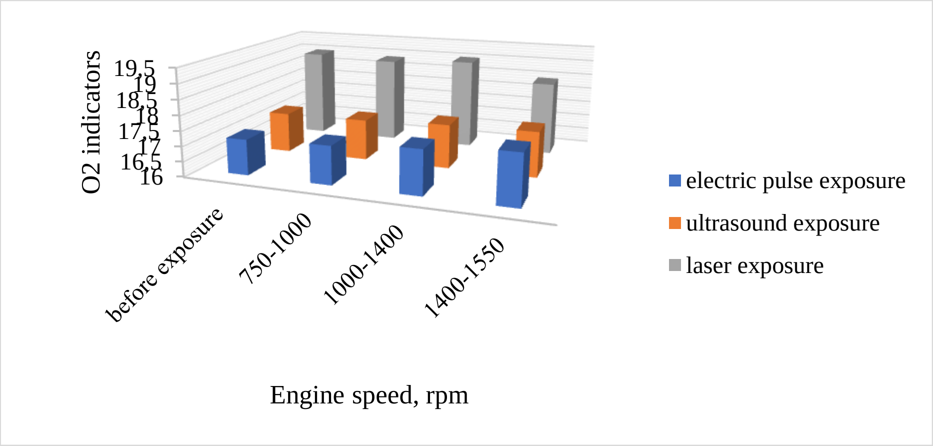


Fig. 4 – Comparison of the efficiency of three types of treatment on O_2 indicators

The results showed that electro-impulse treatment ensures a stable reduction in CO_2 concentration – from 2.38% to 2.10% as engine speed increases, indicating a decrease in the amount of incompletely burned products. At the same time, there is a positive trend in the increase of O_2 concentration – from 17.18% to 17.66%, which indicates more complete combustion of the fuel mixture.

Ultrasonic treatment demonstrated a similar but slightly less pronounced efficiency: CO_2 concentration decreased to 2.18%, and O_2 content increased to 17.50%. Thus, ultrasound has a positive effect, but its impact is inferior to electro-impulse treatment.

Laser treatment showed the highest oxygen content in the exhaust gases – up to 19.01%, which indicates a high level of combustion completeness. However, CO_2 concentration remains at a low level without significant reduction as the engine speed increases, with values stabilizing in the range of 1.35–1.38%. This may indicate an initially cleaner combustion process, but lower sensitivity to changing engine operating conditions.

Additionally, the smoke indicators of exhaust gases were studied as a result of experiments conducted on three test stands. The results of the experiments are presented in Table 4 and in Figure 5.

Table 4. Results of exhaust gas smoke indicators

№	Engine speed	Before (%)	750-1000	1000-1400	1400-1550
			after (%)	after (%)	after (%)
1	Electro-impulse	50	45	36	29
2	Ultrasound	54	35	44	46
3	Laser	80	60	80	60

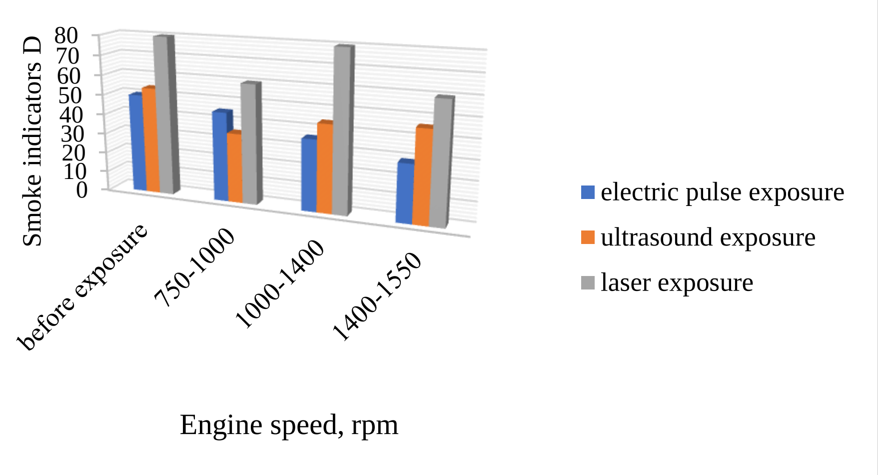


Fig. 5 – Comparison of the effectiveness of three types of treatment on smoke density (D)

The results showed that electro-impulse treatment ensures stable and consistent reduction of pollutant levels as engine speed increases. The value decreased from 50% to 29%, indicating high efficiency of the technology under dynamic engine operating conditions. This suggests good adaptability of the method to varying loads and speeds.

Ultrasonic treatment showed effective pollutant reduction at low engine speeds (down to 35%). However, as the engine speed increased, the smoke level rose again - up to 46% at 1400 - 1550 rpm. This indicates the method's instability under increased loads and a limited effective operating range.

Laser treatment demonstrated an initial reduction in pollution (down to 60% at 750–1000 rpm), but in the mid-speed range (1000–1400 rpm), the effect was neutralized - the smoke level returned to its original value (80%), then dropped again at higher rpm. These fluctuations indicate the method's sensitivity to engine operating modes and the possible need for fine-tuning of the equipment for specific conditions.

Based on the conducted analysis of the experimental results, it can be concluded that the electro-impulse method is the most efficient and stable method for reducing harmful emissions across all considered engine operating modes. It provides the greatest and most consistent reduction in indicators, especially at higher rpm.

Thus, electro-impulse treatment can be recommended as a priority method for integration into diesel engine exhaust gas purification systems.

Based on the conducted research, the design and technical specifications of the electro-impulse muffler were developed. The following recommendations were also made:

– the electrode diameter should not exceed 0.27 m, and the optimal distance between them is 0.32 m;

– to address issues such as electrode burn-out and discharge into the casing, it is recommended to replace the electrodes with automotive spark plugs and to manufacture the muffler casing from dielectric material;

– to increase gas purification efficiency, it is recommended to install two to six spark plugs with electrodes at varying distances inside the muffler;

– the optimal electrode spacing and frequency of electrical impulses were determined for different engine speeds:

– 750 rpm (78.5 rad/s) – 0.008 m, 23.04 Hz;

– 1280 rpm (130.9 rad/s) – 0.004 m, 20.42 Hz;

– 4500 rpm (471 rad/s) – 0.002 m, 46.57 Hz.

The general layout of the proposed electro-impulse muffler, based on the data above, is shown in Figure 6.

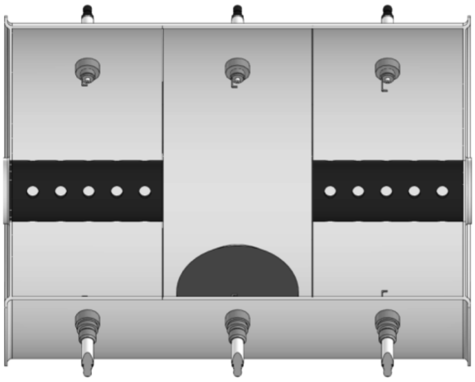


Fig. 6 – Design scheme of the electro-impulse muffler

The obtained results and recommendations require the development of a prototype of an electric pulse muffler and its installation on vehicles for testing in real conditions.

Further development and serial production of electric pulse mufflers will require not only the refinement of their design, but also additional testing in real conditions. Also, the introduction of this technology in the transport industry requires a comprehensive assessment of its financial and environmental efficiency.

The development of a methodology for calculating the economic efficiency of introducing electric pulse mufflers will allow an objective assessment of their competitiveness compared to traditional exhaust gas cleaning systems. This analysis includes a reduction in taxes paid for environmentally harmful emissions, a reduction in fuel consumption due to its complete combustion, as well as environmental benefits.

Thus, for the further development and improvement of the production of electric pulse mufflers, not only engineering and technological aspects are needed, but also a comprehensive economic analysis proving the real commercial feasibility of their mass implementation.

2. Results and discussion

A methodology for calculating the efficiency of implementing an electric pulse muffler has been developed. The presented calculation methodology compared the emission rates of pollutants before and after installing the electric pulse. The possibility of installing them on 540.8 thousand trucks in Kazakhstan is being considered (according to data from the Bureau of National Statistics of Kazakhstan for 2023-2024). The calculation methodology is presented below:

Emission mass before installation of the electric pulse muffler:

$$M_b = \frac{Q \cdot \rho \cdot D_{\mathrm{b}} \cdot T_y \cdot N}{1000} \qquad (1)$$

$$M_b = \frac{10 \cdot 0{,}84 \cdot 0{,}5 \cdot 2628 \cdot 540800}{1000} = 5969134{,}08$$

where Q - fuel consumption per vehicle, l/h;

ρ - density of diesel fuel, kg/l (0.84 kg/l);

D_b - the level of gas smoke before installing an electric pulse muffler (0.5);

T_y - annual work of the car, hours;

N - Number of trucks (540800 units)

Fuel consumption before installing an electric pulse muffler:

$$Q = \frac{R \cdot \vartheta}{100} \qquad (2)$$

$$Q = \frac{25 \cdot 40}{100} = 10$$

where R - average fuel consumption per 100 km, l/100 km (25 l/100 km);

ϑ- average vehicle speed, km/h (40 km/h).

Annual operating time of the vehicle:

$$T_y = T_d \cdot Д_{w.y.} \cdot K_u \qquad (3)$$

$$T_y = 8 \cdot 365 \cdot 0{,}9 = 2628$$

where T_d - daily operating time of the vehicle, hours (8 hours);

$Д_{w.y.}$ - number of working days per year (250-365 days);

K_u - actual utilization factor (0.9).

Emission mass after installation of an electric pulse muffler:

$$M_a = \frac{Q \cdot \rho \cdot Д_a \cdot T_y \cdot N}{1000} \qquad (4)$$

$$M_a = \frac{10 \cdot 0{,}84 \cdot 0{,}29 \cdot 2628 \cdot 540800}{1000} = 3462097{,}76$$

where D_a - Pollution level after system installation (0.29 g/kg).

Reduction of emissions after installation of an electric pulse muffler:

$$\Delta M = M_b - M_a \tag{5}$$

$$\Delta M = 5969134{,}08 - 3462097{,}76 = 2507036{,}32$$

Emissions fee before installing an electric pulse muffler:

$$P_b = M_b \cdot H_{tr} \cdot K \tag{6}$$

$$P_b = 5969134{,}08 \cdot 3538{,}80 \cdot 1{,}26 = 26615700319{,}7$$

where H_{tr} - emission tax rate, tenge/t (109 MCI per 1 ton of the specified fuel - 3538.80 tenge);
К - total coefficient.

Total coefficient:

$$K = K_{tf} \cdot K_e \cdot K_{na} \tag{7}$$

where K_{tf} - coefficient for the type of fuel (diesel - 0.9);
K_e - coefficient up to the economic limit (1.2);
K_{na} - coefficient (1.1–1.5) depending on the presence of a specially protected natural area.

$$K = 0{,}9 \cdot 1{,}2 \cdot 1{,}17 = 1{,}26$$

Emissions Fee After Installing an Electric Pulse Muffler:

$$P_a = M_a \cdot H_{tr} \cdot K \tag{8}$$

$$P_a = 3462097{,}76 * 3538{,}80 * 1{,}26 = 15\ 437\ 106\ 156{,}9$$

Reduction of emission fees after installation of an electric pulse muffler:

$$\Delta P = P_b - P_a \tag{9}$$

$$\Delta P = 26615700319{,}7 - 15437106156{,}9 = 11\ 178\ 594\ 162{,}8$$

Reducing environmental damage:

$$C_d = \frac{Э_d}{M} \tag{10}$$

where C_d - economic losses from 1 ton of emissions (according to WHO and World Bank data). Economic damage from air pollution in Kazakhstan is 10 billion US dollars ≈ 5 trillion tenge;

M – the mass of pollutants emitted into the atmosphere. Every year, 10 million tons of pollutants are emitted into the atmosphere.

$$C_d = \frac{5\ 000\ 000\ 000\ 000}{10\ 000\ 000} = 500\ 000$$

$$E_d = \Delta M \cdot C_d \tag{11}$$

Reducing economic damage:

$$E_d = 2\ 507\ 036{,}32 \cdot 500\ 000 = 1\ 253\ 518\ 160\ 000$$

Fuel economy:

$$E_f = \frac{Q \cdot \Delta \cdot T_y \cdot N \cdot C_{di}}{1000} \tag{12}$$

Smoke reduction percentage ΔD:

$$\Delta \mathrm{D} = \frac{D_b - D_a}{D_b} \cdot 100\% \quad (13)$$

$$\Delta D = \frac{(0{,}5\ -\ 0{,}29)}{0{,}5} \cdot 100\% = 42\%$$

Fuel efficiency:

$$\Delta = \Delta \mathrm{D} \cdot \mathrm{K} \quad (14)$$

where K – conversion factor ≈ 0.5–0.7

$$\Delta = 42\% \cdot 0{,}6 = 25{,}2\%$$

$$E_f = \frac{10\ \cdot\ 25{,}2\ \cdot\ 2628\ \cdot\ 540\,800\ \cdot\ 260}{1000} = 93\,118\,491\,648$$

Calculation of costs for implementation of the system:

$$C_{integ} = P_{inst} \cdot N + C_{ser} \cdot N$$

$$C_{integ} = 80\,000 \cdot 540\,800 + 10\,000 \cdot 540\,800 = 48\,672\,000\,000$$

where P_{ins} – cost of installing one muffler (80,000 tenge);
N - number of vehicles;
C_{ser} – annual service cost (10,000 tenge).

Overall economic effect:

$$E_e = \Delta P + Э_d + E_f - C_{integ} \quad (15)$$

$$Э_d = 11\,178\,594\,162{,}8 + 1\,253\,518\,160\,000 + 93\,118\,491\,648 - 48\,672\,000 = 1{,}357{,}766{,}573{,}810.8$$

Efficiency Ratio:

$$K = Э_e / C_{integ} \quad (16)$$

$$K_e = 1\,357\,766\,573\,810{,}8 / 48{,}672{,}000{,}000 = 27{,}9$$

Relative reduction in emissions:

$$k_1 = \frac{\Delta \mathrm{M}}{M_b} \quad (17)$$

$$k_1 = \frac{2507036{,}32}{5969134{,}08} = 0{,}42$$

Efficiency and profitability of implementation from an environmental point of view:

$$k_2 = \frac{Э_d}{C_{integ}} \quad (18)$$

$$k_2 = \frac{1253518160000}{48672000000} = 25{,}75$$

Fuel Economy Indicator:

$$k_3 = \frac{O_{2(b)} - O_{2(a)}}{O_{2(b)}} \quad (20)$$

$$k_3 = \frac{17{,}66\ -\ 17{,}18}{17{,}18} = 0{,}03$$

Based on the calculations carried out, a graph of changes in the main indicators was drawn up, confirming the feasibility of introducing electric pulse mufflers (Figure 7).

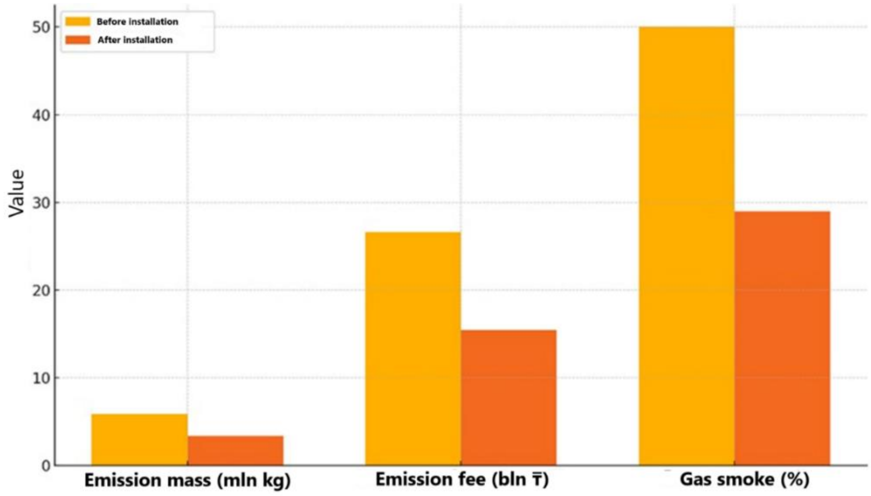


Fig.7. – Graph of changes in indicators before and after installation of an electric pulse muffler

The developed methodology for the implementation of the electric pulse muffler demonstrated its high efficiency in all key indicators, both in the environmental and economic aspects. Calculations showed that the mass of pollutant emissions before the installation of the device was 5969134.08 kg, and after the implementation it decreased to 3462097.76 kg. Thus, it was possible to reduce the volume of emissions by 2507036.32 kg, which is equivalent to a decrease of 42%. This confirms the environmental performance of the proposed solution and its compliance with modern requirements for reducing the negative impact on the environment. At the same time, significant savings were achieved due to the reduction of the emission fee: before the implementation of the muffler, the fee was 26.62 billion tenge per year, and after - 15.44 billion tenge, which made it possible to save 11.18 billion tenge annually. This is a weighty argument in favor of reducing the tax burden on transport enterprises. In addition, according to the World Bank and WHO, the economic damage from air pollution is 500,000 tenge per ton of emissions. Therefore, the prevented environmental damage is estimated at 1.25 trillion tenge per year, which is a significant contribution to environmental protection.

In addition, a 42% reduction in exhaust smoke improved the completeness of fuel combustion, which made it possible to achieve fuel savings of 93.12 billion tenge per year. In total, this formed a total economic effect of 1,357.77 billion tenge. With installation costs of 48.67 billion tenge, the implementation efficiency ratio was 27.9. This means that for every 1 tenge invested in the implementation of mufflers, there is almost 28 tenge of total benefit. This is an indicator of high economic efficiency, proving that the implementation proposal will bring significant returns. Additional evaluation factors also confirm the effectiveness of the technology implementation: the relative reduction in emissions was 42%, the environmental profitability was 25.75, and the fuel economy indicator for oxygen content was 3%. Each tenge invested in mufflers prevents environmental damage by 25.75 tenge. This indicates a high environmental effect and payback even without taking into account fuel savings and taxes. All this allows us to conclude that it is highly feasible to use an electric pulse muffler for modernizing the vehicle fleet and scaling the solution within the framework of the state environmental policy of the Republic of Kazakhstan. Due to the simplicity of the design and reliability of operation, the introduction of electric pulse mufflers into serial production of machine-building plants is promising, especially relevant in the period of limited resources and the transition to "green" technologies.При проектировании электроимпульсного глушителя важно учитывать стоимость материалов, чтобы обеспечить экономичность и доступность устройства. Ниже приведена приблизительная оценка материалов, необходимых для изготовления электроимпульсного глушителя на основе комплектующих для автомобиля ГАЗ-3302 Next с двигателем Evotech 2.7 Евро-5:

Table 5. Estimated cost of materials required for manufacturing electric pulse mufflers

Components	Description	Estimated price (tenge)
Coil	Original models	5000 – 8000
Spark plugs	Original models	7000 – 10000
Insulation materials	Ceramic or heat-resistant plastic insulators	3000 – 5000
Switch housing	Steel or aluminum housing	15 000 – 20 000
Fasteners	Clamps, brackets, rubber supports	3000 – 5000
Electronic control unit	Pulse generator, control electronics	10 000 – 15 000
Wire and connecting elements	High-voltage cables, switches	2000 – 4000
Additional materials	Coatings, sealants, anti-corrosion coatings	2000 – 3000
All		70,000

Catalytic converters cost an average of 500,000 tenge and are widely used, but are limited to partial neutralization. Electric vehicles, completely eliminating carbon emissions, are expensive (about 10 million tenge) and require infrastructure. Thus, based on the above, the introduction of electro-pulse mufflers is the optimal solution.

Conclusion

The conducted study confirmed the high efficiency of electric pulse mufflers for reducing harmful emissions and improving the environmental performance of diesel engines. It was found that the installation of the device provides a reduction in the mass of emissions by up to 42%, a reduction in the fee for emissions by 11.18 billion tenge and the prevention of environmental damage by more than 1.25 trillion tenge per year. Additionally, fuel savings are achieved by increasing the completeness of combustion.

In addition, a comparison with the experimental results obtained on stands with ultrasonic and laser mufflers showed that the electric pulse version is a more energy-efficient, structurally simple and economically feasible solution. It can be adapted to the existing fleet of vehicles without significant design changes.

Also, according to calculations, the efficiency coefficient was 27.9, which demonstrates a high level of profitability of the project. Localization of muffler production at machine-building enterprises of Kazakhstan will stimulate the development of industry, create new jobs and reduce import dependence. Thus, the developed technology has not only scientific and applied, but also strategic significance for the sustainable development of the country's transport sector.

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