IRSTI 73.31.01

Ye. Kryuchkov, A. Kukesheva*, A. Kadyrov, B. Kurmasheva, K. Sinelnikov

Abylkas Saginov Karaganda Technical University, Karaganda, Kazakhstan
*E-mail: *aliya.kukesheva@bk.ru*

Experimental determination on cleaning the exhaust gas of an automobile muffler by an electric pulse

Abstract. Nowadays, creating an environmentally reliable car by reducing the volume of harmful gases in it is a global problem of mankind. For this reason, one of the main areas of research is to improve the exhaust gas cleaning system of internal combustion engines. However, to date, there are no universal designs that would improve the performance of the purification system. In this regard, the development of new vehicle exhaust system designs based on an effective cleaning method is an urgent task. The article highlights the results of scientific and experimental research of the authors on the development of new designs of automobile exhaust muffler working on the basis of the method of electro-pulsed cleaning, designed to reduce the concentration of harmful exhaust gases. The developed experimental installation of the electric-pulse muffler performs gas purification by feeding an electric shock discharge to the electrodes installed in the muffler. The experimental data obtained show changes in the gas transparency depending on changes in the distance between the electrodes. Regression-correlation analysis established empirical dependences of gas transparency values on changes in the distance between the electrodes.

Keywords: car, electric pulse muffler, gas ionization, exhaust system, gas transparency.

DOI: doi.org/10.32523/2616-7263-2023-142-1-23-31

1. Introduction

Today, there is a steadily increasing fleet of vehicles worldwide. The increase in the number of motor vehicles leads to intensive air pollution by exhaust gases. High levels of air pollution have been recorded in megacities and large cities, since most of the passenger cars are concentrated precisely on urban roads and the density of their traffic can increase on average by 200-300 times.

According to statistics for the last two years, just one car on the city's busy roads emits about 800 kg of carbon monoxide (CO), 40 kg of nitrogen dioxide (NO_2) and 200 kg of hydrocarbon (CH) into the air annually. These emissions increase the overall concentration of harmful gas particles, which is the main reason for the lack of clean air in the city, particularly in the narrow streets and adjacent areas to the city's residential buildings. As a consequence of such intensive air pollution, the ecosystem of the city is destroyed and the overall quality of life of city dwellers is reduced [1].

The problem of emission of harmful components of car exhaust gases into the atmosphere requires scientifically substantiated engineering solutions, which involve the development of various designs, working on an effective method of purification in the exhaust system of internal combustion engines. According to the scientific papers in this direction, published in the last few years, many studies have been conducted on the development of auxiliary devices and equipment to the exhaust system. The disadvantages of such developments are the structural complexity of their structural design and low efficiency of exhaust gas purification. In this regard, a different direction in research has been chosen, which is the development of new muffler designs, through the application of an effective method of exhaust gas purification in them.

The aim of the study is to experimentally determine the dependence between the interelectrode distance and the transparency of the exhaust gas after exposure to an electric pulse.

The research hypothesis is the assumption that gas transparency increases with increasing

distance between the electrodes.

The scientific significance is determined by the obtained regression relationship between the transparency and the distance between the electrodes.

2. Methodology

Development of new muffler designs requires a preliminary analysis of existing methods of exhaust gas purification. In the course of such analysis the following purification methods were considered, such as gravitational sedimentation, inertial sedimentation, centrifugal and filtration methods, electric pulse, catalytic, absorption and ultrasonic methods [2]. The general characteristic, namely the advantageous differences and disadvantages of each method are presented in Table 1.

Table 1. Literature analysis of existing methods of gas purification

№	Cleaning methods	General characteristic
1	Gravity deposition	Gravity precipitation is effective only for large particles with diameters greater than 50-100 microns, and the degree of purification is no higher than 40-50%. The method is suitable only for preliminary, coarse gas purification.
2	Inertial deposition	The degree of purification depending on the particle size is 20-70%. The inertial method can only be used for coarse gas purification.
3	Centrifugal methods	The degree of purification for particles with d = 30 μm is up to 80%, and at d = 5 μm it is less than 40%. Cyclones are widely used for coarse and medium gas purification
4	Filtering	Filtration is characterized by high hydraulic resistance and rapid clogging of the filter media with dust
5	Absorption	Absorption methods are characterized by the formation of liquid effluents and cumbersome hardware design. Also this method provides a sufficiently high degree of extraction of harmful impurities only with a large number of purification stages.
6	Catalytic methods	The disadvantage of catalytic purification is the formation of new substances that must be removed from the gas by other methods (absorption, adsorption), which complicates the installation and reduces the overall economic effect.
7	Ultrasonic cleaning	Ultrasonic cleaning makes it possible to precipitate small gas particles which are difficult to trap with conventional apparatuses, also this method is applicable to aggressive gases; it can work at high temperatures and pressures, as well as in compact apparatuses.

According to the results of the analysis, it was found that most of the considered methods are designed for purification of large gas particles and can not fully clean the gases from harmful, small particles. Also many methods can be applied only on large installations, respectively, they can not be applied in a small exhaust system of the car. Only ultrasonic and electric pulse purification methods can affect the smaller particle sizes and allow increasing the efficiency of particle purification by increasing the intensity of coagulation and ionization of particles with their subsequent deposition. However, compared to the coagulation process, the ionization process is much faster, due to the occurrence of a shock discharge between the electrodes, which leads to intensive gas purification from harmful particles. Thanks to the electric pulse method it is possible to achieve rapid and high rates of gas purification, which averages 95%. Consequently, in order to reduce the concentration of toxic and polluting gas substances, the development of new muffler designs based on the electric pulse purification is proposed [3].

In order to develop new designs of mufflers based on electric pulse cleaning, the scientific group of the Department of "Transport Engineering and Logistic Systems" of Karaganda Technical University has developed an experimental installation of electric pulse muffler. Muffler body is made of asbestos, as this material has low electrical conductivity. The installation itself consists of the body 1 of the inlet 2 and outlet 3 holes for passage of exhaust gases; high voltage generator 4; two electrodes 5 mounted inside the body; batten-rail 6 to change the distance between the electrodes. Two electrodes are mounted inside the housing on a special bar rail, to which high voltage electric current is supplied from generator 4 by high-voltage wires (Figure 1).

1 - cylindrical body; 2 and 3 - inlet and outlet holes; 4 - high voltage generator; 5 - two electrodes mounted inside the body; 6 - batten-rail

Figure 1. Experimental installation of electric pulse muffler

Efficiency of operation of the above described unit required experimental confirmation, which was proved by determining values of gas transparency passing through the electropulse muffler. In this regard, experimental studies were carried out in the electropulse unit, the purpose of which was to determine the change in gas transparency from the distance of electrodes in the muffler, installed opposite to each other.

A one-factor experimental plan was made in advance, according to which (n) experiments will be performed at discrete points in time of the input parameter (x) (distance between the electrodes, l) and the corresponding values of the output parameter (y) (gas transparency, p).

The input parameter x is an adjustable parameter, which is set directly by the experimenter, and the output parameter y is the result of n number of experiments. In the experiment the distance between the electrodes will be varied in three different values, according to which the values of gas transparency without influence and with influence of an electric impulse will be determined. As a result 6 experiments will be carried out in the experiment, the number of which is determined by the product of three values of the distance between the electrodes to the number of two exposures to the gas with and without the electric pulse. Thus, it will be possible to make a plan of the experiment, which is presented in the form of a matrix in Table 2.

Table 2. Plan for a single-factor experiment

l	p_1	p_2	y

l_1	l_1p_1	l_1p_2	y_2
l_2	l_2p_1	l_2p_2	y_3
l_3	l_3p_1	l_3p_3	y_4

3. Results and discussion

Experimental studies were carried out as follows. Gas was pumped into the vessel without the pulse and its transparency was measured, then this experiment was repeated when the pulse was applied and the distance between the electrodes was 0.015, 0.02 and 0.025 m. Electrodes that received a shock discharge through a high-voltage generator triggered the process of gas ionization in the electropulse unit. During ionization, the gas was purified from heavy harmful particles, which were subsequently deposited on the inner surface of the muffler. The purified gas was released into the atmosphere through the outlet holes. The degree of gas purification was determined by the gas transparency parameter, which depends on the concentration of harmful particles in the gas. The change in transparency indicates a change in the concentration of harmful particles in the exhaust gas, caused by the deposition of particles on the bottom of the muffler as well. It is possible to record changes in transparency using any device that reacts to changes in illumination, such as a luxmeter. For the experiment, we used a smartphone equipped with an illuminance sensor and Lux Meter v18.12.09 software installed, which allows us to record the value of illuminance (lx) and its changes. A similar experiment was carried out several times with a step-by-step increase in the distance between the electrodes. The results of the experiments are presented in Table 3 and Figure 2.

Table 3. Experimental results

№ of expe-rience	Distance between elec-trodes, m	Frequency of the electrical pulse, Hz	Electrode squareness, %	Gas transparency without electric pulse effect, lx	Gas transparency after exposure to an electric pulse, lx
1	0,015	12,2	33	62	70
2	0,02	12,2	33	75	129
3	0,025	12,2	33	80	247

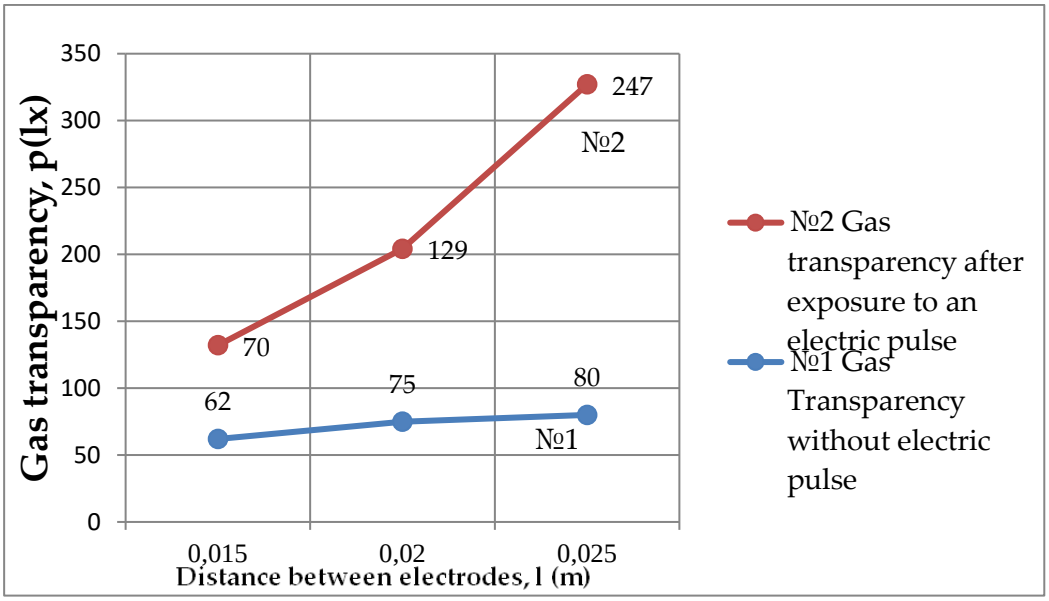

Figure 2. The graph of gas transparency dependence on the distance between the electrodes

Following the results of the experiment regression-correlation analysis of the obtained values of gas transparency y depending on the change of distance between the electrodes x was carried out [4]. The results of the regression-correlation analysis are presented in Table 4.

Table 4. Results of approximation of the gas transparency function p from changes in the distance between the electrodes l

№	Type of regression	Regression equation	Correla-tion coeffi-cient	Deter-mination coeffi-cient	The average error of approxi-mation, %
1	Linear	$y = 17700x - 205.33$	0,98	0,96	11,09
2	Quadratic	$y = 1180000x^2 - 29500x + +247$	1	1	0
3	Stepwise	$y = 2019083.53 \cdot x^{2,45}$	0,99	0,99	4,4
4	Indicative	$y = 10{,}49 \cdot 5.752959604310741e + 54^x$	0,99	0,99	0,85
5	Logarithmic	$y = 1485{,}38 + 339{,}83lnx$	0,97	0,93	14,63
6	Hyperbolic	$y = 478{,}79 - \frac{6{,}32}{x}$	0,94	0,89	17,58
7	Exponential	$y = e^{2{,}35++126{,}09x}$	0,99	0,99	0,85

From the analysis of Table 2 for the highest values of the correlation coefficients, determination and the lowest values of the average error of approximation for the gas transparency p from the change in the distance between the electrodes l, it is proposed to use the quadratic regression equation, equation (1):

$$p = 1180000x^2 - 29500x + 247 \quad (1)$$

Experimental and empirical values of gas transparency p from changes in the distance between the electrodes l are shown in Table 5

Table 5. Experimental and empirical values of gas transparency p from changes in the distance between the electrodes l

Distance between electrodes, m	Experimental values	Empirical values
0,015	70	69,99
0,02	129	128,99
0,025	247	246,99

Plots of dependences of experimental and empirical values of gas transparency p on changes in the distance between the electrodes l are shown in Figure 3

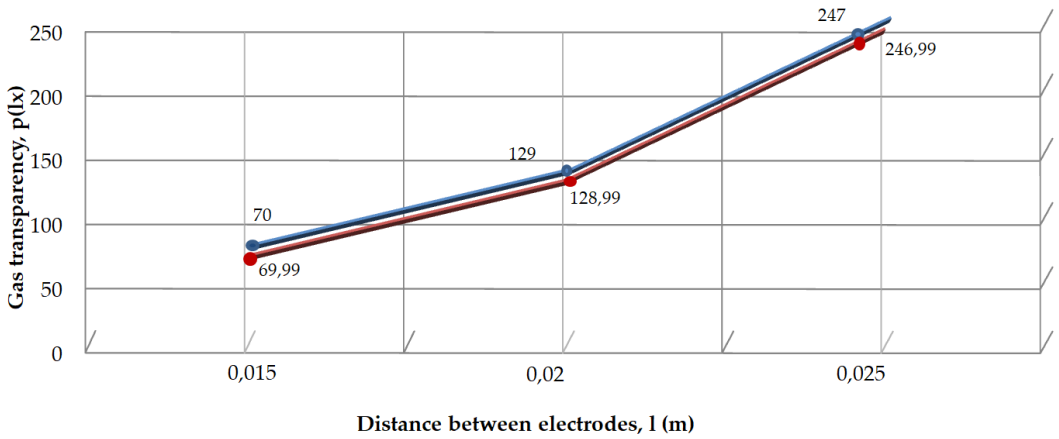

Figure 3. Plots of dependences of experimental and empirical values

The quadratic dependence is the most adequate. The high determinacy of the obtained regression equation allows us to apply mathematical analysis to it.

The rate of determination as a function of the value from (l) is, equation (2):

$$\frac{dP}{dl} = \alpha - \beta\alpha \tag{2}$$

The total increase in transparency $\sum P$ is calculated by a certain integral,where $\alpha = 7058$; $\beta = 295$, equation (3).

$$\sum P = \int_{0,015}^{0,025} (\alpha l^2 - \beta l + 247) \tag{3}$$

$$\sum P = 7058\frac{(0,025-0,015)^3}{3} - \beta\frac{(0,025-0,015)^2}{2} + 247 \cdot (0,025-0,015) = 2,45755$$

Thus, the total increase in transparency is 2,45755 lx.

4. Conclusions

In order to reduce the overall concentration of harmful exhaust gas emissions of a car, it is necessary to apply the method of electro-pulsed exhaust gas purification. The results obtained allow us to determine the optimal distance of the electrodes inside the electro-pulsed muffler, depending on the indicators of gas transparency. From the results of studies, it follows that when the distance between the electrodes increases, there is a sharp increase in the value of the shock discharge, which contributes to a more rapid passage of the ionization process between the gas particles and achieve a high degree of gas purification from harmful particles.

References

1. Durmaz, M., Kalender, S.S., Ergin, S. Experimental study on the effects of ultra-low sulfur diesel fuel to the exhaust emissions of a ferry // Fresenius Environmental Bulletin – 2017. - Vol. 26(10). – P. 5833–5840.

2. Kadyrov A., Kryuchkov E, Sinelnikov K, Ganyukov A., Sakhapov R., Kukesheva A. Studying the process of the internal combustion engine exhaust gas purification by an electric pulse // Communications - Scientific Letters of the University of Zilina. – 2022. - Vol. 24(4). – P. 275-287.

3. Кормина, Л. А. Технологии очистки газовых выбросов: учебное пособие – Барнаул, Изд-во

АлтГТУ. – 2019. — 263 с.
4. Гельман Э., Вехтари А., Хилл Д. Регрессия. Теория и практика. С примерами на R и Stan: -ДМК-Пресс. – 2022. – 271с.

Е.Ю. Крючков, А.С. Кадыров, А.Б. Кукешева, Б.К. Курмашева, К.А. Синельников
Әбілқас Сағынов атындағы Қарағанды техникалық университеті, Қарағанды, Қазақстан

Автокөлік бәсеңдеткішінің пайдаланылған газдарын электр импульспен тазартудың эксперименттік жолмен анықтау

Аңдатпа. Қазіргі уақытта пайдаланылған газдардың зиянды шығарындыларының көлемін азайту арқылы экологиялық сенімді автокөлік құралын құру адамзаттың жаһандық мәселесі болып табылады. Осы себеппен жүргізіліп жатқан ғылыми зерттеулердің негізгі бағыттарының бірі іштен жану қозғалтқыштарының пайдаланылған газдарын тазарту жүйесін жетілдіру болып табылады. Дегенмен, бүгінгі күнге дейін іштен жану қозғалтқыштарының пайдаланылған газдарын тазарту жүйесінің жұмысын жақсартатын әмбебап құрылымдар мен тиімді әдістер жоқ. Осыған байланысты тиімді тазалау әдісі негізінде автокөліктің газ шығару жүйесінің жаңа құрылымдарын әзірлеу өзекті міндет болып табылады. Мақалада авторлардың автокөліктің зиянды шығарындыларының концентрациясын төмендетуге арналған электр-импульсті тазарту әдісі негізінде жұмыс істейтін автокөлік бәсеңдеткішінің жаңа құрылымдарын жасау бойынша ғылыми және эксперименттік зерттеулерінің нәтижелері келтірілген. Бәсеңдеткіштің ішіне орнатылған электродтарға соққы электр разрядын беру арқылы газ бөлшектерінің иондану процесін жеделдететін автокөліктердің пайдаланылған газдарын тазарту принципін жүзеге асыратын электр импульсті бәсеңдеткіштің эксперименттік қондырғысы сипатталған. Электродтар арасындағы қашықтықтың өзгеруіне байланысты газ мөлдірлігі көрсеткіштерінің өзгеруі бойынша эксперименттік деректер алынды. Соның нәтижесінде жүргізілген регрессиялық-корреляциялық талдау негізінде газдың мөлдірлігі мәндерінің электродтар арасындағы қашықтықтың өзгеруіне эмпирикалық тәуелділіктері анықталды.

Түйін сөздер: автокөлік, пайдаланылған газды шығару жүйесі, электроимпульсты бәсеңдеткіш, газдың иондануы, газдың мөлдірлігі.

Е.Ю. Крючков, А.С. Кадыров, А.Б. Кукешева, Б.К. Курмашева, К.А. Синельников
Карагандинский технический университет имени Абылкаса Сагинова, Караганда, Казахстан

Экспериментальное определение степени очистки выхлопного газа автомобильного глушителя электроимпульсом

Аннотация. В настоящее время создание экологически надежного автотранспортного средства посредством уменьшения в нем объема вредных выбросов выхлопных газов является глобальным вопросом человечества. По этой причине одним из главных направлений, по которому ведутся научные исследования, является совершенствование системы очистки отработавших газов двигателей внутреннего сгорания. Однако на сегодняшний день нет универсальных конструкций и эффективных методов, которые позволили бы улучшить работу системы очистки выхлопных газов двигателей внутреннего сгорания. В связи с этим разработка новых конструкций системы выпуска газов автомобиля на основе эффективного метода очистки является актуальной задачей. В статье представлены результаты научных и экспериментальных исследований авторов по разработке новых конструкций автомобильного глушителя, работающих на основе метода электроимпульсной очистки, предназначенных для снижения концентрации вредных выбросов отработавших газов автомобиля. Описана экспериментальная

установка электроимпульсного глушителя, реализующая принцип очистки выхлопных газов автомобилей за счет ускорения процесса ионизации частиц газа посредством подачи ударного электрического разряда на электроды, вмонтированные внутри глушителя. Получены экспериментальные данные по изменению показателей прозрачности газа в зависимости от изменения расстояний между электродами. Таким образом, были установлены эмперические зависимости значений прозрачности газа от изменения расстояний между электродами на основе проведенного регрессионно-корреляционного анализа.

Ключевые слова: автомобиль, электроимпульсный глушитель, ионизация газа, система выпуска отработавших газов, прозрачность газа.

References

1. Durmaz, M., Kalender, S.S., Ergin, S. Experimental study on the effects of ultra-low sulfur diesel fuel to the exhaust emissions of a ferry, Fresenius Environmental Bulletin, 26(10), 5833–584(2017).
2. Kadyrov A., Kryuchkov E, Sinelnikov K, Ganyukov A., Sakhapov R., Kukesheva A. Studying the process of the internal combustion engine exhaust gas purification by an electric pulse, Communications - Scientific Letters of the University of Zilina, 24 (4), 275–287(2022).
3. Kormina, L.A. Tekhnologii ochistki gazovy`kh vy`brosov: uchebnoe posobie [Technologies for cleaning gas emissions] (Barnaul, Izd-vo AltGTU, 2019, 263 p) [in Russian].
4. Gel`man E., Vekhtari A., Khill D. Regressiya. Teoriya i praktika. S primerami na R i Stan [Regression. Theory and practice. With examples on R and Stan] (DMK-Press, 2022, 271 p) [in Russian].

Information about authors:

Ye. Kryuchkov – PhD student of the 3rd year, Department of "Transport equipment and Logistic Systems", Transport and Road Faculty, Abylkas Saginov Karaganda Technical University, 56 Nursultan Nazarbayev ave., Karaganda, Kazakhstan.

A. Kadyrov – Doctor of Technical Sciences, Professor, Department of "Transport equipment and Logistic Systems", Transport and Road Faculty, Abylkas Saginov Karaganda Technical University, 56 Nursultan Nazarbayev ave., Karaganda, Kazakhstan.

A. Kukesheva - PhD student of the 2nd year, Department of "Transport equipment and Logistic Systems", Transport and Road Faculty, Abylkas Saginov Karaganda Technical University, 56 Nursultan Nazarbayev ave., Karaganda, Kazakhstan.

B. Kurmasheva - Candidate of Technical Sciences, Associate Professor, Department of "Transport equipment and Logistic Systems", Transport and Road Faculty, Abylkas Saginov Karaganda Technical University, 56 Nursultan Nazarbayev ave., Karaganda, Kazakhstan.

K. Sinelnikov - PhD student of the 3rd year, Department of "Transport equipment and Logistic Systems", Transport and Road Faculty, Abylkas Saginov Karaganda Technical University, 56 Nursultan Nazarbayev ave., Karaganda, Kazakhstan.

Е.Ю. Крючков – 3 курс докторанты, «Көлік техникасы және логистикалық жүйелер» кафедрасы, жол-көлік факультеті, Әбілқас Сағынов атындағы Қарағанды техникалық университеті, Нұрсұлтан Назарбаев даң., 56, Қарағанды, Қазақстан.

А.С. Кадыров – т.ғ.д., профессор, «Көлік техникасы және логистикалық жүйелер» кафедрасы, жол-көлік факультеті, Әбілқас Сағынов атындағы Қарағанды техникалық университеті, Нұрсұлтан Назарбаев даң., 56, Қарағанды, Қазақстан.

А.Б. Кукешева – 2 курс докторанты, «Көлік техникасы және логистикалық жүйелер» кафедрасы, жол-көлік факультеті, Әбілқас Сағынов атындағы Қарағанды техникалық университеті, Нұрсұлтан Назарбаев даң., 56, Қарағанды, Қазақстан.

Б.К. Курмашева – т.ғ.к., доцент, «Көлік техникасы және логистикалық жүйелер» кафедрасы, жол-көлік факультеті, Әбілқас Сағынов атындағы Қарағанды техникалық

университеті, Нұрсұлтан Назарбаев даң., 56, Қарағанды, Қазақстан.

К.А. Синельников – 3 курс докторанты, «Көлік техникасы және логистикалық жүйелер» кафедрасы, жол-көлік факультеті, Әбілқас Сағынов атындағы Қарағанды техникалық университеті, Нұрсұлтан Назарбаев даң., 56, Қарағанды, Қазақстан.

Е.Ю. Крючков – докторант 3 курса, кафедра «Транспортная техника и логистические системы», транспортно-дорожный факультет, Карагандинский технический университет имени Абылкаса Сагинова, пр. Нурсултана Назарбаева, 56, Караганда, Казахстан.

А.С. Кадыров – д.т.н, профессор, кафедра «Транспортная техника и логистические системы», транспортно-дорожный факультет, Карагандинский технический университет имени Абылкаса Сагинова, пр. Нурсултана Назарбаева, 56, Караганда, Казахстан.

А.Б. Кукешева - докторант 2 курса, кафедра «Транспортная техника и логистические системы», транспортно-дорожный факультет, Карагандинский технический университет имени Абылкаса Сагинова, пр. Нурсултана Назарбаева, 56, Караганда, Казахстан.

Б.К. Курмашева – к.т.н., доцент, кафедра «Транспортная техника и логистические системы», транспортно-дорожный факультет, Карагандинский технический университет имени Абылкаса Сагинова, пр. Нурсултана Назарбаева, 56, Караганда, Казахстан.

К.А. Синельников – докторант 3 кафедра «Транспортная техника и логистические системы», транспортно-дорожный факультет, Карагандинский технический университет имени Абылкаса Сагинова, пр. Нурсултана Назарбаева, 56, Караганда, Казахстан.