Environmental safety diagnosis and maintenance specific of heavy vehicles and buses engines functioning with compressed natural gas

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Abstract. The results of a statistical survey of the content of toxic components CO, CH and NOX in the exhaust gases of 38 “LiAZ” buses (4th and 5th ecological classes with foreign-made engines) at the nominal and increased engine crankshaft rotation speeds in idle running at compressed (compressed) natural gas in Moscow and adjacent areas of the region. It has been established that, as a first approximation, these modes provide information on the deterioration of environmental safety, primarily in relation to nitrogen oxide (NOx) emissions, the control of which in ordinary operation by the existing technical regulations for all types of vehicles, including heavy-duty gas vehicles are not provided. Statistical processing, with an assessment of the maximum permissible value of this diagnostic parameter in two idle modes (no more than 50 M-1 for the best attainable states of buses of the 5th ecological class), showed that the absence of such a simple control leads to approximately 75% of faulty states. These indicators can be significantly improved with the introduction of monitoring of operational monitoring of NOx and the development of more complex maintenance technologies. Herewith there is a significant environmental safety improvement of gas motor buses in comparison with diesel versions (approx. 6-8 times) and the technological and economic feasibility of their use for many regions of the country. Preliminary studies of the structure of such a technology have been carried out on a “KAMAZ” gas vehicle, which has an engine control different from “LiAZ” buses. At the same time, the higher NOX emissions level could be considered as allowable for intercity bus transportation and for activities outside the city, however, they can be reduced by about 3...5 times due to the use of the latest versions of pre-chamber devices "Ball Lightning".

1. Introduction

The Order of the Government of the Russian Federation No. 767-r [1] dated May 13, 2013 gave a new impetus to public transport gasification. According to this Order up to 50 % of buses and municipal heavy vehicles in million cities should be converted to the operation on natural gas (methane) as a motor fuel within the period of 7 years. It was planned that for settlements over 300 thousand inhabitants the share of buses and municipal heavy vehicles running on natural gas would be 30%, and for settlements over 100 thousand inhabitants – 10%. The reason of the issuance of the Order was not
only economic criteria (the cost of methane for various regions of Russia is 2.5 - 3 times lower compared to the cost of gasoline and diesel fuel), but also a considerable contribution to the solution of the problem concerning to the protection of environment from the harmful effect of automotive transport (i.e., elimination of exhaust smoking, this phenomenon is unavoidable for diesel engines running under load. In recent years, there has been a trend to switch light motor vehicles to natural gas. First of all, it relies to taxi, but in southern regions of the country many private cars’ owners are already using natural gas as a motor fuel. Conversion of vehicles to natural gas using gas-diesel process did not give a high replacement rate in urban traffic conditions. By the time the Order of the Government of the Russian Federation [1] was issued, this problem had been begun to solve successfully by factory production of specialized mono-fuel gas engines for buses LiAZ, NefAZ, Volgabus, PAZ, KavZ and trucks KamAZ and Ural. Other disadvantages that hinder the widespread use of methane, experts attribute the insufficient number of gas refuelling stations. According to the latest data, for more than 200 thousand motor vehicles running on compressed natural gas (CNG) in Russia there are slightly more than 500 CNG stations (automobile gas-filling compressor stations) and refueling sites for cars equipped with mobile auto-gas stations (PAGZ). At the same time for cars and light commercial vehicles using liquefied petroleum gas (propane-butane) the number of gas refuelling stations is 3500 units. In addition, maintenance and repair processes become more complicated due to the need to maintain gas equipment. Technogenic safety performance also deteriorates due to the need to store the filled gas under high pressure (20 MPa) [3]. However, the intensity of the public transport gasification processes, in spite of the noted problems, has recently increased significantly, primarily for Moscow, which is the largest city in Europe and has a circular layout that is not the most convenient for natural ventilation. State Unitary Enterprise “Mosgortrans” increases purchases of new LiAZ gas buses with foreign engines with higher environmental performance [7]. Simultaneously there is the growth of the fleet of more expensive electric buses for operation in the central regions of Moscow. In accordance with the Resolution of the Moscow Government dated April 22, 2019 No. 408-PP "On Approval of the General Gas Supply Scheme for the City of Moscow for the Period up to 2030 and the Scheme for External Gas Supply for the City of Moscow for the Period Until 2030" [2] in a short time (until 2020 year) 11 new CNG refuelling stations were built, and 9 more CNG stations are operating in the Moscow region. At present, there is a situation with an insignificant work load of Moscow CNG refuelling stations. All this contributes to the further growth of the methane car fleet in the near future. This poses an additional task of developing processes for organizing diagnostics and maintenance of heavy trucks and buses gas engines in order to maintain operation environmental safety at the certification requirements level set by the manufacturer, or even higher, in accordance with the state-of-the-art achievements of scientific and technical progress (STP).

2. Statement of the problem and analysis of possible methods of its solution

In connection with the latter, it becomes obvious to revise the previously established ideas about the environmental safety of heavy vehicles and buses, and technical regulations in force in the field of technical operation to ensure it. In particular, one of the authors of this publication [11] showed the feasibility, in addition to smoke, of additional control for city buses of the content of nitrogen oxides \(NO_x\) in the exhaust gases, which carry independent information about the ecological state of the rolling stock and specify the already known list of technological operations to improve it ... Somewhat earlier [10] it was shown the feasibility of an additional operational check of diesel passenger cars and light commercial vehicles (LDDVs) for their compliance with the EURO environmental classes using a simplified method of simulating driving cycles on unloaded running drums, which was also based on \(NO_x\) measurement. To do this, for a start, it is necessary to provide in the technical regulations for equipping motor transport enterprises (MTE) and service stations with five-channel gas analyzers, which have long been produced in Russia by commercial organizations at lower (compared to Western) prices and with better adaptation to our operating conditions. Direct measurements focus on certain harm to public health and the environment (eutrophication), which can increase when the normative values for \(NO_x\) emissions are exceeded, established by the standards of different countries (for the EU,
the EURO standards). The relevance of emission control is confirmed by the so-called "Dieselgate" in the United States, when Volkswagen AG underestimated the actual values of exhaust gases toxic parameters for cars during certification. In the West, various types of studies are constantly being carried out related to the assessment of the harmful affect from excess NOx emissions from LDDVs, which give a significant scatter of values when using different approaches (for example, 900-500-300 [10] when assessing the total harm).

However, for the three noted approaches, there is a practical coincidence of the estimates of the comparative ranking according to the main indicators of pollution: for example, for Germany, the annual emission of particulate matter and soot was last estimated at 2800 conventional values, ozone (causing smog) at 1550, and NOx at 930 [12], i.e., the latter accounted for more than 20% of the total pollution damage for diesel passenger cars, which is unacceptable.

There is no doubt that for heavy-duty vehicles and buses with diesel engines, damage assessments may have also significant indicators (according to conventional estimates “10” for Germany is about 30% less compared to LDDVs), therefore, all measures of the Moscow Government on the intensive transfer of city buses to the use of methane are justified. However, for these machines, the significance of NOx emissions increases significantly due to the increase in compression ratio compared to gasoline engines, and the worse operating conditions for classic three-way catalytic converters due to excessive depletion of the combustion mixture. Therefore, along with the recommendations for diesel buses, it is necessary to monitor NOx emissions level in exhaust gases when using methane as motor fuel, which is not provided for by the current technical regulations [6]. It is also advisable to supplement the complex of operational diagnostics by checking the operation of spark plugs, the role of which may turn out to be even more significant in comparison with gasoline cars (due to an increase in breakdown voltages), and fuel consumption, at least at idle. For these purposes, it is possible to use both recently appeared and practically well-mastered, but little-known diagnostic equipment: the latter should include the USB Autoscope (models II-III-IV), which can be used to check the operation of the spark plugs on the oscillograms of the secondary voltage. Convenient for measuring fuel consumption during stationary diagnostics are ELM 327 adapters, which are connected to the universal diagnostic connectors EOBD and OBDII of the car and display the fuel consumption (l / h) and ignition timing on the mobile phone, and the intensity of braking and acceleration of the car when driving; in the long term (after equipping the car with appropriate sensors), the content of toxic NOx and greenhouse CO2 components in exhaust gases, and other indicators can be determined. All of the above will make it possible to move to a higher level of maintenance of the environmental safety of gas buses (and heavy vehicles), and, according to the authors, in the social and possibly economic direction, will justify the complication and rise in the cost of maintenance technology. Optimization of these processes will become possible after a complex of laboratory and industrial research, the initial stage of which is devoted to this work. The accumulated experience shows that the necessary stage of such research in the field of technical operation of vehicles (TOV), providing an important source of information, are statistical surveys of the condition of vehicles in the MTE [4, 8, 9].

3. Experimental research.

The collection of statistical information was carried out at the Levoberezhnaya operational site of the Zelenogradskiy branch of the Mosgortrans State Unitary Enterprise (the former 11th Bus Depot in Moscow), which operates LiAZ gas buses equipped with various engines. To measure the composition of exhaust gases at idle speed at a warm engine at the diagnostic site, a five-channel gas analyzer of the 2nd accuracy class of Russian Federation production was used, which was provided by the Department of Operation and servicing of motor vehicles «MADI». Measurements were an integral part of the educational process of preparing the attestation work of the master's student of the department, which provided the necessary level of reliability in the further processing of the results obtained. The indicators of the content of CO, CO2, CH and NOx obtained for 38 buses at two idle modes are given in Table 1 and can be used with repeated independent processing by interested specialists.
Table 1. Environmental indicators of “LiAZ” gas buses when working on idling modes at $n_1 = 700$ rpm (1) and $n_2 = 1600$ rpm (2)

|         | CO, % (1) | CO$_2$, % (1) | CH, M$^{-1}$ (1) | NO$_X$, M$^{-1}$ (1) | CO, % (2) | CO$_2$, % (2) | CH, M$^{-1}$ (2) | NO$_X$, M$^{-1}$ (2) | Env. class |
|---------|-----------|---------------|-----------------|----------------------|-----------|---------------|-----------------|----------------------|------------|
| 0.318   | 10.64     | 56            | 1630            | 1.271                | 10.28     | 64            | 1052            | 5                    |
| 0.32    | 10.82     | 72            | 1140            | 0.265                | 11.35     | 60            | 870             | 5                    |
| 0.005   | 10.41     | 82            | 117             | 0.017                | 11.29     | 53            | 258             | 5                    |
| 0       | 10.76     | 145           | 340             | 0                    | 11.56     | 31            | 919             | 4                    |
| 0       | 11.12     | 126           | 463             | 0                    | 11.48     | 21            | 373             | 5                    |
| 0       | 10.91     | 21            | 297             | 0.004                | 11.28     | 20            | 569             | 5                    |
| 0.002   | 10.97     | 29            | 352             | 0                    | 10.93     | 20            | 625             | 5                    |
| 0.004   | 11.08     | 10            | 594             | 0.002                | 11.2      | 7             | 287             | 4                    |
| 0       | 10.82     | 71            | 429             | 0.007                | 11.33     | 11            | 37              | 5                    |
| 0       | 11.56     | 0             | 411             | 0                    | 11.44     | 0             | 6               | 5                    |
| 0       | 11.47     | 11            | 548             | 0                    | 11.55     | 9             | 28              | 5                    |
| 0.001   | 10.21     | 45            | 1445            | 0.001                | 10.81     | 18            | 1918            | 4                    |
| 0.009   | 11.48     | 42            | 476             | 0.014                | 11.52     | 14            | 129             | 5                    |
| 0.001   | 11.02     | 80            | 134             | 0.01                 | 11.64     | 35            | 375             | 4                    |
| 0       | 10.95     | 41            | 353             | 0                    | 11.24     | 27            | 2053            | 4                    |
| 0       | 9.255     | 0             | 336             | 0                    | 9.075     | 1             | 469             | 5                    |
| 0.011   | 8.318     | 9             | 26              | 0.006                | 7.934     | 5             | 13              | 5                    |
| 0       | 7.589     | 5             | 211             | 0                    | 6.539     | 5             | 49              | 5                    |
| 0.002   | 7.22      | 0             | 8               | 0.003                | 7.529     | 4             | 51              | 5                    |
| 0.002   | 7.24      | 25            | 262             | 0.001                | 7.005     | 11            | 1136            | 4                    |
| 0.001   | 6.704     | 4             | 12              | 0.001                | 6.257     | 6             | 10              | 5                    |
| 0.001   | 7.064     | 0             | 7               | 0.001                | 6.794     | 2             | 101             | 5                    |
| 0.008   | 8.801     | 10            | 333             | 0.007                | 8.686     | 12            | 627             | 4                    |
| 0       | 7.25      | 1             | 4               | 0.008                | 6.961     | 2             | 11              | 5                    |
| 0.001   | 7.133     | 0             | 13              | 0.001                | 6.757     | 1             | 9               | 5                    |
| 0       | 6.111     | 14            | 256             | 0                    | 6.916     | 20            | 348             | 4                    |
| 0       | 6.93      | 21            | 478             | 0.001                | 6.476     | 13            | 1171            | 4                    |
| 0       | 11.43     | 1             | 754             | 0                    | 11.53     | 1             | 26              | 5                    |
| 0.059   | 11.33     | 3             | 226             | 0.025                | 11.56     | 3             | 211             | 5                    |
| 0.013   | 11.5      | 0             | 420             | 0.013                | 11.61     | 0             | 8               | 5                    |
| 0       | 11.27     | 0             | 510             | 0                    | 11.45     | 3             | 450             | 5                    |
| 0.001   | 11.44     | 0             | 428             | 0                    | 11.57     | 2             | 587             | 5                    |
| 0       | 11.43     | 13            | 1402            | 0                    | 11.45     | 8             | 2124            | 4                    |
| 0       | 10.08     | 138           | 459             | 0                    | 10.35     | 38            | 3074            | 4                    |
| 0       | 11.64     | 2             | 1202            | 0                    | 11.63     | 2             | 0               | 5                    |
| 0.002   | 11.41     | 1             | 50              | 0.002                | 11.47     | 6             | 5               | 5                    |
| 0.005   | 11.2      | 7             | 409             | 0.005                | 11.35     | 10            | 424             | 5                    |
| 0       | 11.46     | 1             | 3               | 0                    | 11.51     | 1             | 9               | 5                    |

The analysis was carried out using the Russian and the English versions of program STATISTICA-10.12.5. All indicators were transferred to a specialized spreadsheet (see below). The figures below show the results of processing the data from Table 1 obtained using these programs.

At the same time, it is convenient to set the automatic execution of calculations by comparing two independent samples based on t-tests (Fig. 1), from which one can clearly see the significant environmental advantage of buses of the 5th ecological class (in relation to the 4th) in terms of NO$_X$ emissions, especially on increased frequencies at which load modes are in operation. (From Table 1 it follows that CO and CH emissions for gas buses are practically insignificant for environmental safety).
Another important conclusion that can be made after the regression analysis (according to the spreadsheet in Fig. 2) is the identification of a fairly close probabilistic (stochastic) effect of NO\textsubscript{X} emissions at nominal idle modes on emissions at increased frequencies. (According to the numerical estimates on the information panel in Fig. 2, the correlation coefficient exceeded the critical value R>0.5 and the determination R\textsuperscript{2}>0.25; Fisher’s criterion, reflecting the informativeness of the regression dependence, reached a significant value F>12 at a high level of significance, reflecting the probability obtaining an erroneous conclusion p<0.00148, therefore the line for the influence coefficient B1 by the STATISTICA program is highlighted in red). Hence, an important conclusion for practice follows that it is possible (and advisable) to use both the first and second indicators of NO\textsubscript{X} emissions at idle modes as independent diagnostic parameters, and when they are in the range of maximum permissible values, consider a gas vehicle in an ecologically sound state. However, it must be remembered that this conclusion does not correspond to the specifics of checking gasoline cars, for foreign models of which, at the XXth century, zeroing of NO\textsubscript{X} values for environmental classes EURO-3 and higher is already observed (sensitivity of an inexpensive gas analyzer of the 2nd accuracy class is not sufficient); here it is necessary to carry out speed tests on unloaded running drums, which already show NO\textsubscript{X} emissions.

![Span diagram for assessing the average NO\textsubscript{X} emissions of «LiAZ» gas buses of EURO-4 and EURO-5 ecological classes at idle mode at nominal (left) and increased frequencies (right) of engine crankshaft rotation](image.png)

**Figure 1.** Span diagrams for assessing the average NO\textsubscript{X} emissions of «LiAZ» gas buses of EURO-4 and EURO-5 ecological classes at idle mode at nominal (left) and increased frequencies (right) of engine crankshaft rotation

In a mass inspection of the state of vehicles, it is advisable to determine the maximum permissible values of diagnostic parameters on the basis of a statistical approach, gradually excluding the worst values from the initial array, until the remainder of the best and already achieved in practice indicators are obtained, the dispersion of which can be approximated with the greatest probability by unimodal theoretical laws. Such laws can be normal, exponential, gamma distribution with positive and negative skewness, and sometimes Weibull, although the latter was developed for assessing reliability indicators. The validity of this approach can be seen from the histograms in Fig. 3, built in accordance with the statistics requirements (Sturges criterion), the left of which shows the entire range of values of NO\textsubscript{X} emissions at an increased crankshaft speed for “LiAZ” buses of the 5th ecological class, where the first column clearly reflects the presence of a zone of good health, and the remaining five with practically the same probability density - faulty. Subsequent analysis of the data for the 1st column in the range up to 65 M\textsuperscript{-1} (set by a special command) allowed the STATISTICA program to establish the only possible approximation of the distribution by the Weibull law (middle part of Fig. 3), the limitation of which with a probability of 0.95 in the first approximation allows set the maximum allowable value of the diagnostic parameter (no more than 50 M\textsuperscript{-1} according to the calculations on the probabilistic calculator). The same value is given by calculations for the nominal idle mode. From data...
analysis of table 1 it can be seen that even for buses of the 5th ecological class, about 25% of cars are formally serviceable in two parameters (informally, in terms of the main parameter for increased frequency - about 45%), and performing routine maintenance operations on them would lead to a decrease in emissions. Although these standards turned out to be impracticable for 4 class of buses, such statistical gradations will also help to reduce environmental pollution. In general, in terms of NOX emissions at nominal idle modes, there is a noticeable advantage of “LiAZ” 5th ecological class gas buses compared to diesel buses (Fig. 4): here, for the first 15% of cars, emissions above 800 M-1 could be easily reduced to average values of 400 M-1.

Figure 2. STATISTICA-12.5 program window with the estimation of the parameters of the linear model of the regression dependence of NOX nitrogen oxide emissions at increased crankshaft speeds on emissions at nominal frequencies for “LiAZ” gas buses of the EURO-5 ecological class
Figure 3. Histograms of the distribution of NOX emissions values of “LiAZ” gas buses of the EURO-5 ecological class at idle modes at increased engine crankshaft speeds for a mixed sample (serviceable and faulty condition) (on the left, fitting the law is impossible); after excluding the faulty state data based on a statistical approach (middle); at nominal frequencies after excluding faulty state data (right).

Figure 4. Histograms of the distribution of the content of nitrogen oxides NOX in the exhaust gases of “LiAZ” city buses running on compressed natural gas (CNG) of the declared EURO-5 ecological classes, and “LiAZ” city buses with diesel engines of the EURO-4-5 [11] declared ecological classes, on nominal speed of the crankshaft at

The need (and expediency) of using a more complex technology for servicing systems to ensure the operability of high-power gas engines (in this case, ignition systems, methane supply and exhaust gas neutralization) was confirmed by the example of diagnosing a “KAMAZ” vehicle equipped with EControls engine control system. First of all, it was carried out to assess the feasibility of using prechamber devices “Ball Lightning” (Fig. 5, left [8]) on such engines, the use of which on gasoline cars led to a decrease in NOX emissions by 1.5 times (when imitating an urban driving cycle (ECE test) on the running drums without load [5]). In addition, the modernized pre-chamber device made it possible to use ordinary “Zhiguli” spark plugs with increased gaps, since the breakdown voltage was reduced by about 30% (Fig. 5, right), which also turned out to be relevant for methane engines with an
increased compression ratio using foreign plug models. Unfortunately, the USB Autoscope device, which allows observing the secondary voltage oscillograms through a laptop, has the ability to sequentially check the operation of the spark plug for only one cylinder (by reinstalling the capacitive sensor on the high-voltage wires), however, with two operators at the diagnostic site, this does not cause complications.

![Image of a spark plug](image)

**Figure 5.** Section of the prechamber device "Ball Lightning" (for flare ignition of a combustible mixture in the cylinders of gasoline engines) with an experimental spark plug with an extended central electrode (left) [8, 9], and the distribution of breakdown voltage indices of gapless spark plugs BRISK PREMIUM LR15ZC when using a prechamber device a) and when working without it (b) on a VAZ-2107 car engine (right)

The measurements of the diagnostic indicators of the "KAMAZ" vehicle were carried out when it was parked in an open area at a temperature of 17°C Celsius, which ensures the operability of the devices. At the same time, it turned out to be possible to record the relative changes in fuel consumption (without preliminary calibration of the measuring system) when the ELM 327 adapter (for cars) is connected to the universal OBDII diagnostic connector of the "KAMAZ" car and displays the instantaneous fuel consumption (l/h) and the ignition timing on the mobile phone (and a large set of other indicators in the process of movement). The results of three consecutive stages of measurements (initial state, using the pre-chamber device "Ball Lightning" with gapless BRISK candles, repetition of the initial state) are given in tab. 2. The excess air coefficient $\alpha$ for an excessively lean mixture was calculated from $\text{CO}$, $\text{CO}_2$ and $\text{CH}$ using the Porsche formula [5], since it went beyond the gas analyzer settings. From the operational analysis table 2, it can be seen that the environmental performance of the "KAMAZ" vehicle as a whole is somewhat worse compared to "LiAZ" buses of the 4th environmental class, due to a sharp, more than 100 times, increase in $\text{NO}_x$ emissions at an increased rotational speed of the KV, but they can be reduced by $3 \ldots 5$ times when using pre-chamber devices (the latter can be assumed for "LiAZ" buses). In addition, during servicing, you can additionally correct the breakdown voltage of the spark plugs by individually adjusting the gap (to increase the spark power), and the ignition timing, since it was observed to change by (-5) degrees when using pre-chamber devices. According to the data obtained, an increase in fuel consumption for prechamber devices was not revealed, although (as it was mentioned above) when a passenger car was running on liquefied natural gas (propane-butane), efficiency deteriorated by 5%, and on gasoline - up to 10%. Thus, the tested prechamber devices are an ideal means of significantly increasing the environmental safety of gas engines of public transport vehicles, and with an increase in the efficiency of the $\text{NO}_x$ neutralization systems, they can provide an increase in their service life. A higher level of estimation of $\text{NO}_x$ emissions can be obtained with the additional use of a stationary stand with unloaded treadmills, on which a classic imitation of an urban driving cycle (ECE test) for passenger cars with high-speed sites of 15, 30 and 50 km/h, typical for urban traffic, is possible. The
development of a model for recalculating the results obtained in indicators of specific emissions by mass of matter in \(g/km\) of run per 1 liter of the working volume of the engine, as was already justified for diesel buses “LiAZ” [9].

**Table 2.** Changes in the environmental and technical performance of the gas engine of a “KAMAZ” vehicle at nominal and increased idle speed when using gapless plugs BRISK PREMIUM LR15ZC in combination with prechamber device “Ball lightning” [8, 9]

| Device, operating mode: \(n, \text{rpm}\) | Emissions \(CO, \%\) | Emissions \(CO_2, \%\) | Emissions \(CH, M^1\) | Emissions \(NO_X, M^4\) | Fuel consumption \(G_T, l/h\) | Excess air ratio \([5]\) \(\alpha, \text{rel.units}\) |
|-----------------------------------------------|------------------|------------------|------------------|------------------|------------------|------------------|
| Without device, 700                         | 0.044            | 8.45             | 144              | 28               | 13.9             | 1.52             |
| Without device, 1600                        | 0.124            | 9.00             | 240              | 2850             | 25.0             | 1.41             |
| Prechamber, 700                             | 0.032            | 8.54             | 136              | 45               | 12.4             | 1.51             |
| Prechamber, 1600                            | 0.124            | 9.70             | 131              | 410              | 22.2             | 1.35             |
| Without device, 700                         | 0.034            | 8.55             | 140              | 12               | 13.1             | 1.51             |
| Without device, 1600                        | 0.124            | 9.25             | 274              | 1614             | 22.8             | 1.37             |

4. Conclusion
The absence in operation of checking the composition of exhaust gases from heavy-duty gas vehicles and buses with five-channel gas analyzers (for \(CO, CO_2, CH, NO_X\) and \(O_2\)) does not allow timely detection of the deterioration of their environmental safety and high-quality maintenance (MO) in order to reduce emissions into the environment the main polluting component - nitrogen oxides \(NO_X\). At the same time, the probability of a malfunctioning state, according to preliminary estimates obtained by the authors, can reach values of the order of 55 .. 75%, which reduces the effectiveness of the current program of the Moscow Government to transfer 50% of public transport to methane, with already developed infrastructure for the supply of this type of fuel. Achievements of scientific and technological progress of the last 2-5 years makes it advisable and allows the use of more complex maintenance technologies based on complex diagnostics of ignition systems, fuel supply, neutralization devices and other necessary elements in the chains of the technological process, ensuring the maintenance of environmental safety of buses when working on the line on the level of significantly more expensive electric buses. The complication and rise in the cost of service, according to the authors, in the future will be multiplied by an increase in social and economic efficiency. The latter is also facilitated by the specific use of prechamber devices "Ball Lightning" for high-power gas engines, which reduce \(NO_X\) emissions by 3 .. 5 times (due to changes in the combustion processes of the fuel mixture) and increase the service life of the neutralizers in operation.

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