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Reducing the environmental threat of motor vehicles by converting engines for operating on natural gas

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The article explains the necessity of using natural gas (NG) for motor vehicle diesel engines, which makes it possible to reduce their environmental threat and to save motor oil fuel. The composition of the NG used and its physic-chemical properties are presented in the article. In order to determine and to optimize the amount of the NG supplied for motor diesel engines, the authors of the article have tested them on the electro-brake testing bench SAK-N670, which has a balanced pendulum and the weighing machine "Rapido". At the same time, the toxicity level of the exhaust gases (EG) was determined using an automatic gas analysis system "ASGA-T", and the smoke intensity of the exhaust gas was estimated using an optical-electric reflectometer "Bosch EFAW-68A". It has been experimentally established that for the NG using in the tested motor vehicles diesel engines, it is necessary to maintain the following ratio of components: gas should be 80%, diesel fuel filling should be 20%. When converting diesel engine 4F 11.0/2.5 installed on trucks and tractors of urban public utilities to NG, and while the simultaneous use of exhaust gas recirculation (EGR) in it at a rate of 20% (EGR is applied to eliminate the increased nitrogen oxides as a result of using NG), the content of nitrogen oxides (NO_x) in EG is reduced by 30.0–30.1%, carbon soot is reduced by 82.0–88.7%; carbon dioxide (CO_2) is decreased by 31.6–35.6%. When converting a diesel engine 4FC 11.0/12.5 installed on city passenger buses to NG, in the EG a decrease in NO_x content by 5.5–35.1% occurs; carbon soot decreases by 88.2–92.0%; carbon monoxide (CO) decreases by up to 21.6%. The conversion of these motor diesel engines to work on NG, in addition to improving the environmental performance of their EG indicators, also helps to save oil motor fuel in the amount of 80%.

Keywords: natural gas, exhaust gases, diesel, ecology of city.

УДК 631.4

Снижение экологической опасности автомобилей конвертацией на природный газ

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Обоснована необходимость использования природного газа (ПГ) для дизелей автотранспортных средств, что позволяет уменьшить их экологическую опасность и сэкономить моторное нефтяное топливо. Представлен состав используемого ПГ и его физико-химические свойства. В целях разработки, определения и оптимизации количества подаваемого ПГ для автотранспортных дизелей проведены их испытания на электротормозном стенде SAK–N670 с балансирной маятниковой машиной и весовым механизмом «Rapido». При этом токсичность отработавших газов (ОГ) определялась при помощи автоматической системы газового анализа «АСГА–Т», а дымность ОГ оценивалась с помощью оптико-электрического рефлектомера «Bosch EFAW–68A». Экспериментально установлено, что для применения ПГ в исследуемых автотранспортных дизелях необходимо поддерживать следующее соотношение компонентов: газ – 80%, запальная порция дизельного топлива (ДТ) – 20%. При конвертации на ПГ дизеля 4Ч 11,0/12,5, устанавливаемого на грузовые автомобили и тракторы городских коммунальных служб, и одновременного применения в нём рециркуляции отработавших газов (РОГ) в размере 20% (РОГ применена для ликвидации возросших в результате применения ПГ оксидов азота) происходит снижение содержания в ОГ оксидов азота (NO_x) на 30,0–30,1%, сажи – на 82,0–88,7%; диоксида углерода (CO_2) – на 31,6–35,6%. При конвертации на ПГ дизеля 4ЧН 11,0/12,5, устанавливаемого на городские пассажирские автобусы, происходит снижение содержания в ОГ NO_x от 5,5 до 35,1%, сажи – на 88,2–92,0%; монооксида углерода (CO) – до 21,6%. Перевод указанных автотранспортных дизелей для работы на ПГ, кроме улучшения экологических показателей их ОГ, позволяет также экономить нефтяное моторное топливо в размере 80%.

Ключевые слова: природный газ, выхлопные газы, дизельное топливо, экология города.

Currently, most of the world's population lives in cities with overloading of urban areas. It is essential that it results in problems concerning the deterioration of people's living conditions, the growth of diseases, a drop in labor productivity, a decrease in life expectancy, pollution of the environment, and climatic changes. So, as a result of urbanization, there is considerable pressure on the lithosphere, which leads to a change in the relief, karst voids formation, violation of river basins, desertification of areas that become unsuitable for the life of plants, animals and people. Intensive destruction of flora and fauna takes place, their diversity decreases, the number of natural and recreational zones, green plantations also decreases, and the so-called "urban nature" arises [1–4].

Rivers and lakes are polluted with industrial and domestic waste water. All this leads to a reduction of water areas, extinction of aquatic plants and animals. Also, all the planet's water resources (groundwater, intracontinental hydro systems, etc.) are being contaminated. One of the consequences is a shortage of drinking water, which, among other things, causes the death of thousands of people on the planet [5–8]. Air pollution is one of the first environmental problems that have been discovered by the mankind. The atmosphere is polluted with the car exhaust gases, industrial emissions. Cars overflow urban and suburban transport routes. All this leads to dusty atmosphere, acid rains. Subsequently, dirty air causes diseases of people and animals. As forests are being cut down intensively, the number of plants that absorb carbon dioxide reduces. Household garbage is another source of soil, water and air pollution. Different materials are decomposed for a long time. The disintegration of certain substances requires from 200 to 500 years. And while the process of their refining is underway, harmful components are released and they cause numerous diseases. Also, noise, radioactive pollution, and the problems of a city municipal utilities functioning are relevant [9–12].

It seems that this list can be continued endlessly, therefore in the article we will define one of the most critical environmental problems for cities. So, according to the Health Ministry of the Russian Federation in large industrial centers of Russia, atmospheric air pollution is caused by toxic emissions of motor vehicles in the 70–80% of cases. Of course, in Russia there is the relevant environmental legislation and regulations for reducing the toxic components in the exhaust gases of vehicles and internal combustion engines, and Russia has international obligations in the field of environmental protection, adopted during the signing of the international agreements in the field of environmental protection to reduce harmful emissions, but in order to improve the ecological situation in the Russian cities, it is necessary to convert the vehicles for working on natural gas in a large scale [13–15].

So, according to the Order of the Russian Government No. 767, adopted on May 13, 2013, "On the expansion of using natural gas as a motor fuel", the Ministry of Industry and Trade, the Ministry of Regional Development, the Ministry of Transport and the Ministry of Energy of Russia are tasked to develop and submit to the Russian Government a set of measures concerning the creation of conditions for bringing the level of natural gas (NG) using as motor fuel for public road transport and transport of municipal road services by 2020 in the subjects of the Russian Federation [16]:

a) in the cities with the population of more than 1 million people this level should be increased up to 50% of the total number of equipment units;

b) in the cities with the population over 300 thousand people it should be increased up to 30% of the total number of equipment units;

c) in the cities and settlements with the population of more than 100 thousand people it should be increased up to 10% of the total number of equipment units.

In addition, on April 18, 2018, the President of the Russian Federation V.V. Putin in Novo-Ogarevo held a meeting with the Government members. During the discussion he has determined the unconditional priority of natural gas motor fuel over other fuel types [17].

Therefore, we believe that the NG usage for improving the environmental performance of automobile transport is more than relevant.

The purpose of this work is the rationale of NG using in diesel engines to improve their environmental performance and to save oil motor fuel.

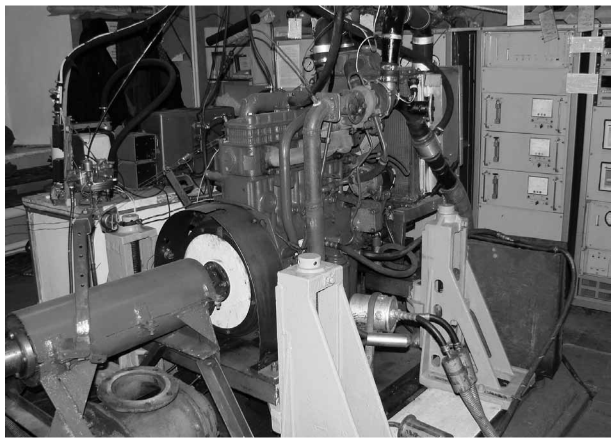
Objects and methods of research

In the Vyatka State Agricultural Academy on the basis of the Department of Heat Engines, Vehicles and Tractors, we have carried out the research of diesel engines in order to convert them to work on NG [18, 19]. The experimental setup consisted of the tested diesel engine, the electro-brake testing bench SAK-N670, which has a balanced pendulum and the weighing machine "Rapido" (Fig. 1b), and other measuring equipment.

The toxicity level of the exhaust gases was determined using an automatic gas analysis system "ASGA-T" in accordance with the Russian State Standards GOST R 41.49-2003 and the GOST 17.2.2.05-97. When determining the smoke intensity, a filtration method was used. The blackening of the filter was estimated by the degree of its optical reflection in comparison with the pure filter and was measured with the help of the optical-electric reflectometer "Bosch" EFAW-68A. Sampling for determining the smoke intensity of exhaust gases was carried out taking into account the requirements of the GOST R 41.24-2003 and the GOST 17.2.2.02-98. During the bench tests, summer diesel fuel (GOST 305-2013) and compressed natural gas of the "Yamburg" deposit from the "Yamburg-Tula" gas pipeline have been used (Table 1) [18]. The used gas was in cylinders in accordance with the GOST 27577-2000 (Table 2) [20].

When converting diesel engines to work on NG, their operation was implemented according to the following scheme. The natural gas cylinder was fed into the diesel through the intake system together with the air in the form of a homogeneous mixture that was compressed, and at the end of the compression a primer portion of diesel

a



b

Fig. 1. Control panel for brake testing bench SAK–N670 (a) and experimental diesel 4FC 11.0/12.5 (b)

Table 1

The composition of natural gas used in the bench tests (Yamburg deposit, "Yamburg – Tula" gas pipeline) [18]

Substance	Content, %
Methane	98.27
Ethane	0.62
Propane	0.18
Butane	0.05
Pentane	0.01
Nitrogen	0.81
Oxygen	0.01
Carbon dioxide	0.05

Table 2

Physical and chemical indicators of natural gas in accordance with the State Standard GOST 27577-2000 [20]

The Name of the indicator	Value
The low heat value, bulk, kJ/m^3, no less	31800
Concentration of water vapors, mg/m^3, no more	9.0
The volume fraction of oxygen, %, no more	1,0
The total volume fraction of non-combustible components, %, no more	7.0
Weight of mechanical impurities in 1 m^3, mg, no more	1.0
The concentration of mercaptan sulfur, g/m^3, no more	0.036
The concentration of hydrogen sulfide, g/m^3, no more	0.02
Calculated octane number (motor method), no less	105
Relative density to air	0.55–0.70

fuel was injected into this high-temperature mixture, and the resulting heterogeneous mixture self-ignited. Thus, when using natural gas with a primer portion of diesel fuel, an oil diesel fuel replacement, equal to 80%, has been achieved.

Results and discussion

Natural gas, the main component of which is methane (CH_4), has long found its niche of being used as a motor fuel in motor vehicles, because as motor fuel it has undeniable environmental advantages compared to traditional petroleum fuels.

Figures 2 and 3 (see color insert) show the results of studies of the high-speed and load bearing characteristics of the environmental compatibility of the EG of the diesel engine 4F 11.0/12.5, installed on trucks and tractors of urban public services and which uses NG.

Analyzing the graphs of the toxic components content when working on NG including the exhaust gas recirculation (EGR) depending on the change in the engine speed (Fig.3), it can be noted that the pattern of the curves corresponds to the diesel process, with only their numerical values being changed. Thus, the NG using in the range of the engine speed change from 1400 to 2400 min^{-1} leads to the decrease in the content of carbon soot in the EG by 83.6–88.7%; to the decrease of CO by 20.8–65.5%; to the decrease of CO_2 by 47.0–49.4%. But it results in the growth of NO_x by 23.5–25.9% and C_xN_y by 75.0–85.3%. The EGR has been used to eliminate the increased nitrogen oxides as a result of using the NG. Thus, when working on gas-diesel fuel with 10% EGR, the NO_x content closely corresponds to the diesel fuel, and the simultaneous use of NG and EGR at a rate of 20% leads to a decrease in the NO_x content in the exhaust gases by 30.0–30.1%, carbon soot – by 82.0–88.7%; CO – by up to 51.7%; CO_2 – by 31.6–35.6%.

The analysis of the load bearing characteristics (Fig. 3) shows that the NG using in the diesel engine 4 F 11.0/12.5 leads to an increase in the content of NO_x and C_xH_y in the exhaust gases. The EGR using reduces the NO_x content in the exhaust gases in the entire load range. Thus, when working on NG with the EGR 40%, in the range of load changes from 0.13 to 0.26 MPa, the NO_x decreases by up to 55.0%, and when working on NG with the EGR 20% at the nominal mode (p_e = 0.64 MPa), the content of NO_x in the EG is lower by 31.8% compared to the diesel fuel. The use of the EGR 10% reduces the C_xN_y to 9.9% in relation to the work on NG without EGR. It should be noted that a significant increase in C_xH_y at high loads is due to the incomplete combustion of fuel in conditions of the lack of oxidizer with the increase in the degree of EGR.

When working on NG, the concentration of carbon soot and CO_2 in the EG is significantly reduced. So, for example, in the nominal mode, the use of NG with the EGR 20% reduces the carbon soot by 81.0% in EG and it reduces CO_2 by 35.8%. The content of CO in the EG when working on NG including the EGR increases at small and medium loads, and with an increase in the load over the nominal one, a decrease occurs. So, in the nominal mode of operation for NG with the EGR of 20%, this decrease is 14.3%.

Figures 4 and 5 (see color insert) show the results of studies of the speed and load bearing characteristics of the environmental compatibility of the diesel engine 4FC 11.0/12.5 of the passenger bus "PAZ". This engine operates on NG.

Analyzing the changes in the exhaust gases toxicity level according to the rotational speed, it can be noted that when working on NG the NO_x content in the EG is lower than when working on diesel fuel in the entire range of rotational speeds. Thus, the NG using in the range of rotational speed change from 1200 to

2400 min^{-1} leads to the decrease in the content of carbon soot by 88.2–92.0% in the EG; to the decrease in NO_x by 5.5–35.1% and to the decrease of CO by up to 21.6% at speed of more than 2100 min^{-1}. But at this time the growth of C_xH_y by 95.0–98.3% and the growth of CO by up to 5.0% at a rotation frequency of less than 2000 min^{-1} takes place.

The study of the load-bearing environmental characteristics of the working process of the transport diesel engine 4FC 11.0/12.5 operating on NG (Fig. 5) shows that the NG using in this diesel engine reduces the content of carbon soot and NO_x in the EG in the entire range of load variation, and it also reduces CO when the average effective pressure (p_e) is less than 0.7 MPa. However, in this case, the growth of total hydrocarbons C_xH_y in the entire investigated load interval has been noted. So, at the nominal operating mode (p_e = 0.84 MPa), the use of NG leads to a decrease in the carbon soot in the EG of diesel engine by 91.7%, in NO_x by 8% and in CO by 19.0%.

Conclusion

The authors of the article have given a promising solution for improving the environmental performance of diesel engines by converting them for operating on NG.

When converting diesel engine 4F 11.0/2.5 installed on trucks and tractors of urban public utilities to NG, and while the simultaneous use of EGR at a rate of 20%, the content of nitrogen oxides (NO_x) in the EG is reduced by 30.0–30.1%; carbon soot is reduced by 82.0–88.7%; carbon dioxide (CO_2) is decreased by 31.6–35.6%.

When converting a diesel engine 4FC 11.0/12.5 installed on city passenger buses to NG, a decrease in NO_x content in the EG by 5.5–35.1% occurs, carbon soot decreases by 88.2–92.0%; carbon monoxide (CO) decreases by up to 21.6%.

The conversion of these motor diesel engines to work on NG, in addition to improving the environmental performance of their EG indicators, also helps to save oil motor fuel in the amount of 80%.

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