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Study of Loading Regimes of Diesel Engines Operating on Natural Gas

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Abstract

The study of the working process of diesel engines operating on natural gas in a wide range of operating modes is relevant, first of all, in order to further their implementation on transport and transport-technological machines. The paper discusses and justifies the methods of supply of natural gas in automotive diesel engines. On the basis of the analysis of materials of the experimental tests which are carried out at chair of thermal engines of cars and tractors of the Vyatka state agricultural Academy results of researches of effective and ecological indicators of the diesel engines D-240 (4F 11.0/12.5), D-245.12S (4FC 11.0/12.5) with turbocharged, D-245.7 (4FC 11.0/12.5) with cooling of the pressurized air working at natural gas are presented. The possibilities of these diesel engines in solving the problems of reducing the toxicity of exhaust gases, as well as the impact of the use of natural gas on their environmental characteristics.

In order to determine and optimize the basic parameters of diesel engines were carried out their bench tests when working on diesel fuel and natural gas. Application of natural gas in diesel engines reduces the content of toxic components in exhaust gases in the nominal operating mode: in diesel D-245.12S turbocharged nitrogen oxides by 6.0%, carbon black by 25 times, carbon monoxide by 1.2 times; in diesel D-245.7 with cooling of charge air nitrogen oxides by 23.1%, carbon black by 2.1 times; in diesel D-240 with exhaust gas recirculation (EGR is applied for reliable reduction increased as a result of the use of natural gas nitrogen oxides) nitrogen oxides by 43.2%, soot by 5.6 times, carbon dioxide by 33.3%, carbon oxides by 10.0%.

Keywords: diesel, natural gas, turbocharging, exhaust gas recirculation, toxicity, exhaust gases.

FORMULATION OF INVESTIGATED PROBLEM

The directions of further development of diesel engines for transport and transport-technological machines largely depend on the prospects of using various energy resources in them. As a raw material base for the production of existing and promising fuels for diesel engines can be used as non-renewable energy sources-minerals (oil, gas, coal, etc.) and renewable resources-vegetable oils, animal fats, biomass, wood, agricultural and household waste, etc. [1-5].

Natural gas is one of the most promising energy carriers for transport and transport-technological machines. The global demand for natural gas has been met for 70 years with proven cost-effective reserves of 136 trillion m^3. While the average annual world production of natural gas equal to about 2 trillion m^3. Russia has 45% of the world's gas reserves, and Russia's gas production complex continues to be the most dynamically developing industry, which determines the growth of the national economy [6].

In diesel, natural gas serves in the following way. The gas is mixed with air in the mixer-dispenser installed in the inlet pipeline and enters the cylinders. Liquid fuel is supplied through the regular fuel system at the end of the compression stroke. On the basis of such a diesel engine, it is possible to create a gas engine in which gas is supplied to the cylinders, and ignition occurs with the help of a spark plug. The advantage of the gas engine is the ability to work completely on gas, excludes liquid fuels, and the lack of need for major structural changes requiring rework of diesel.

To transfer the operation of diesel to natural gas with ignition from the fuse portion of diesel fuel does not require significant alteration and readjustment of the engine. With this method, you must set the mixer on the intake pipeline, to develop the system of regulation of the gas supply to connect it with the gas valves. The degree of compression of the diesel engine, as a rule, remains unchanged. Optimal adjustments of the installation angle of advance of fuel injection and supply of the shut-off portion of diesel fuel, which can remain constant or vary depending on the speed and load, are selected experimentally. The changes in the regulator are mainly related to the design of the throttle actuator, the installation of the stop supply of the fuse portion of diesel fuel and fuel type switches. This diesel engine is equally suitable for operation on natural gas with a pilot dose of diesel fuel and pure diesel process, which is one of the significant advantages of modernization [7-10].

Comparing the means of transfer of diesel to natural gas, it should be noted that, with respect to chetyrekhtomnym automotive diesels the most simple and economical, allowing the use of natural gas not only newly designed but also already in operation is a method of operating a diesel on gas diesel process with gas injection during the intake stroke in the intake tubing with the ignition of the gas mixture from the ignition portion of diesel fuel sent regular fuel equipment at the end of the compression stroke. It is this method and has its development in automotive diesel engines [11-14].

EXPERIMENTAL STUDIES

In the Vyatka state agricultural Academy at the Department of heat engines, automobiles and tractors conducted bench testing automotive diesel engines D-240 (4F 11.0/12.5), D-245.12S (4FC 11.0/12.5), turbocharged, D-245.7 (4FC 11.0/12.5) with intermediate cooling of charging air to natural gas for gas-diesel process [15]. During the bench tests of the engine, natural gas of the Yamburgskoye deposit from the Yamburg−Tula gas pipeline was used, which included the following substances (Table 1).

Table 1. The composition of natural gas used in the test bench (Oilfield Yamburgskoye, gas pipeline Yamburg - Tula)

Name	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

The content of toxic components in the exhaust gases of diesel engine 4F 11.0/12.5 depending on the load variation is shown in figure 1.

The graphs show that the use of natural gas in diesel 4F 11.0/12.5 leads to an increase in the content of nitrogen oxides in exhaust gases. Thus, at the nominal operating mode, this increase is 31.8%, and at re = 0.13 MPa, the emission of nitrogen oxides increases by 53.9%. The use of EGR reduces the content of nitrogen oxides in exhaust gases over the entire load range. When working on the gas-diesel process with EGR 40% in the load range from 0.13 to 0.26 MPa, NO_x decreases from 1.9 to 2.6 times in relation to the gas-diesel process and from 19.2 to 55.0% in relation to diesel. At operation of the gas diesel at the nominal mode with the EGR 10%, the NO_x content in the exhaust gases is lower by 24.1% of the gas-diesel process and corresponds to the diesel process.

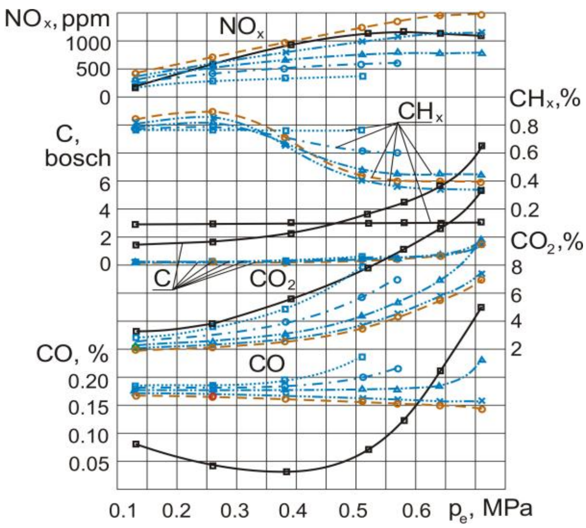

Figure 1. The effect of natural gas on the exhaust emissions of a diesel engine 4F 11.0/12.5 depending on load variation at n=2200 min^{-1} and $\Theta_{inj}=23^o$:
– diesel fuel; - gas-diesel fuel; - gas-diesel fuel with EGR 10%; - gas-diesel fuel with EGR 20%; - gas-diesel fuel with EGR 30%; - gas-diesel fuel with EGR 40%

The use of natural gas causes an increase in the total hydrocarbon content in the entire range of load changes. So, at p_e=0.13 MPa the CH_x increase is from 0.09 do 0.84%, or 9.3 times, and at p_e=0.71 MPa increase is from 0.11 to 0.40%, or 3.6 times. The use of EGR causes an ambiguous effect on the total hydrocarbon content of exhaust gases. At work of the gas diesel with EGR 40% on small loadings from 0.13 to 0.26 MPa there is a decrease in CH_x from 8.7 to 14.5% in relation to gas-diesel process, but at p_e=0.51 MPa there is an increase almost on 50%. The content of soot in the exhaust gases is significantly reduced when working on the gas-diesel process. The use of natural gas with a EGR 10% at p_e=0,64 MPa leads to a decrease in the soot content in relation to the diesel process from 5,8 to 1,0 Bosch, or 5,8 times.

The use of natural gas with EGR results in a decrease in CO_2 throughout the load range. During operation of the diesel engine with EGR 40% at p_e=0,26 MPa leads to a decrease in CO_2 from 3.8 to 3.4%, or 10.5%. When working with gas diesel EGR 10% with p_e=0.64 MPa leads to a decrease in CO_2 from 10.9 to 5.9%, or 45.9%. The use of natural gas with EGR causes an increase in CO at low loads and a decrease in the maximum and close to them. It should be noted that a significant increase in the total hydrocarbons at high loads is due to incomplete combustion of the fuel in the conditions of a lack of oxidizer with an increase in EGR.

The load characteristics of the change in the content of toxic components in exhaust gases of the turbocharged diesel engine 4FC 11.0/12.5 are shown in figure 2.

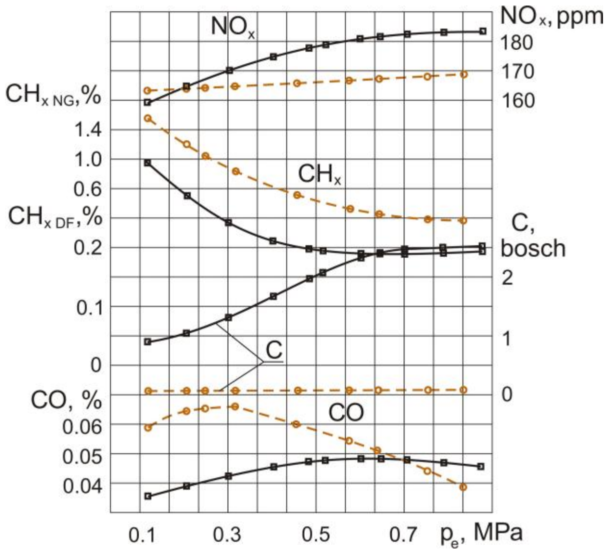

Figure 2. The effect of natural gas on the exhaust emissions of a diesel engine 4FC 11.0/12.5 depending on load variation at n=2400 min^{-1} and $\Theta_{inj}=11^o$:

– diesel fuel; - gas-diesel fuel

Analyzing the graphs (figure 2), It can be noted that the NO_x content in the exhaust gases during the work on the gas-diesel process is lower than in the entire range of load changes. So at p_e=0.84 MPa NO_x content decreases by 6.4% (from 183 to 172 ppm). The reduction is achieved by reducing the duration of the combustion process when working on natural gas. The content of soot in exhaust gases is significantly reduced when working on the gas-diesel process over the entire load range. In the diesel process, the maximum content of particulate matter is 2.5 Bosch and the diesel engine is 25 times less. This is because the methane gas of all the fuels, the least prone to soot formation. When working on the gas-diesel process, the content in the exhaust gases increases AT low and medium loads. As the load increases, the content of CO in the exhaust gases during operation on the gas-diesel process decreases and at an average effective pressure of 0.7 MPa equals the content of CO in the exhaust gases of the diesel process, and with a further increase in the load lies below the values of the diesel process.

Analyzing the content of the total CH_x hydrocarbons in the exhaust gases, it should be noted that the content significantly increases with the reduction of the load and reaches a maximum when the load is discharged to a mode close to idling. The content of CH_x in the exhaust gases of the diesel engine is 0.01% (p_e=0.84 MPa), and when working on natural gas, the content of CH_x in the exhaust gases of the engine is already 0.20%, which is 20 times more. This is explained by the fact that the total hydrocarbons and carbon monoxide are products of incomplete combustion, the increase in their percentage in the exhaust gases is influenced by the deterioration of the combustion process at low loads due to the overfilling of the gas-air mixture due to the use of a qualitative method of power control and ignition with As a result, at low loads, the process of spreading the flame front and the entire combustion process as a whole proceeds more slowly, contributing to incomplete combustion of the fuel and, as a consequence, the deterioration of the effective efficiency.

Load characteristics of the content of toxic components in diesel 4FC 11.0/12.5 cooled charge air are shown in figure 3.

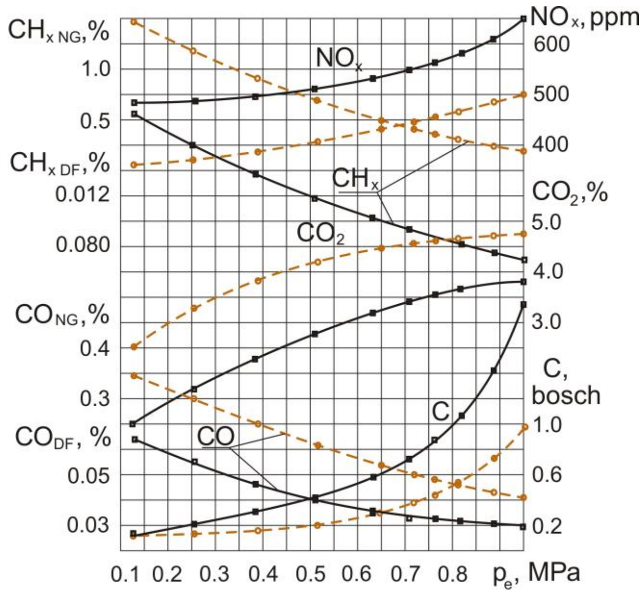

Figure 3. The effect of natural gas on the exhaust emissions of a diesel engine 4FC 11.0/12.5 turbo depending on load variation at n=2400 min^{-1}:

– diesel fuel; - gas-diesel fuel

When a diesel engine works on natural gas at the optimum installation angles of an advancing of injection of fuel (Θ_{inj}=7º to work on natural gas and Θ_{inj}=9º to operate on diesel fuel) the content of NO_x in the exhaust gas lower than that of the diesel with diesel fuel in the entire range of loads. At p_e=0.947 MPa, NO_x content in exhaust gases decreases by 23.1% (from 650 ppm to 500 ppm).

The fluidity of exhaust gases during operation of the diesel engine on natural gas in the whole range of loadings significantly decreases. Thus, when working on the diesel process, the maximum fluidity of exhaust gases is 1.95 Bosch, and when working on natural gas diesel 0.95 Bosch, that is 2.1 times less.

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CONCLUSION

Based on the laboratory and bench studies of working processes of diesel engines D-240 (4F 11.0/12.5), D-245.12S (4FC 11.0/12.5), turbocharged, D-245.7 (4FC 11.0/12.5) with intercooling the possibility to improve their environmental performance, save diesel fuel by the use of natural gas. So, the use of natural gas in diesel engines reduces the content of toxic components in exhaust gases in the nominal mode: in diesel 4FC 11.0/12.5 nitrogen oxides by 6.0%, carbon black by 25 times, carbon monoxide by 1.2 times; in diesel 4FC 11.0/12.5 with cooling of pressurized air nitrogen oxides by 23.1%, soot by 2.1 times; in diesel 4F 11.0/12.5 with exhaust gas recirculation nitrogen oxides by 43.2%, soot by 5.6 times, carbon dioxide by 33.3%, carbon oxides by 10.0%.

REFERENCES

[1] Chang W.R., Hwang J.J., Wu W. Environmental impact and Sustainability study on Biofuels for Transportation Applications // Renewable and Sustainable Energy Reviews. 2017. T.67. P. 277-288.

[2] Sustainable biodiesel production from oleaginous yeasts utilizing hydrolysates of various non-edible lignocellulosic biomasses / A. Patel, N. Arora, K. Sartaj [et al.] // Renewable and Sustainable Energy Reviews. 2016. T. 62. P. 836-855.

[3] Quality control of biodiesel content of b7 blends of methyl jatropha and methyl crambe biodiesels using mid-infrared spectroscopy and multivariate control charts based on net analyte signal / B.V. Sitoe, H. Mitsutake, E. Guimaraíës [et al.] // Energy and Fuels. 2016. T.30. No.2. P. 1062-1070.

[4] Datta A., Mandal B.K. Impact of Alcohol Addition to Diesel on the Performance Combustion and Emissions of a Compression Ignition Engine // Applied Thermal Engineering. 2016. T.98. P. 670-682.

[5] Arent, D.J. Wise A., Gelman R. The status and prospects of renewable energy for combating global warming // Energy Economics. 2011. V.33. Issue 4. July. P. 584-593.

[6] Markov V.A., Loboda S.S., Kamaltdinov V.G. Optimization of diesel fuel and corn oil mixtures composition // Procedia Engineering. Ser. 2. International Conference on Industrial Engineering. "ICIE 2016". 2016. P. 225-234.

[7] Diesel-to-natural gas engine conversion with lower compression ratio / G.G. Ter-Mkrtichyan, A.M. Saikin, K.E. Karpukhin [et al.] // Pollution Research. 2017. Vol. 36. No. 3. P. 678-683.

[8] Progress and perspectives in converting biogas to transportation fuels / L. Yang, X. Ge, Y. Li [et al.] // Renewable and Sustainable Energy Reviews. 2014. T. 40. P. 1133-1152.

[9] Research progress in the development of natural gas as fuel for road vehicles: a bibliographic review (1991-2016) / M.I. Khan, T. Yasmeen, M. Farooq [et al.] // Renewable and Sustainable Energy Reviews. 2016. T. 66. S. 702-741.

[10] Zgodziński T. Evolution of using gas fuel for motor cars and accompanying dangers for users // Bezpieczenstwo i Technika Pozarnicza. 2012. T. 26. S. 53-66.

[11] Mikulski M., Wierzbicki S. Numerical investigation of the impact of gas composition on the combustion process in a dual-fuel compression-ignition engine // Journal of Natural Gas Science and Engineering. 2016. T. 31. S. 525-537.

[12] Chai X., Mahajan D., Tonjes D. J. Methane emissions as energy reservoir: context, scope, causes and mitigation strategies // Progress in Energy and Combustion Science. 2016. T. 56. P. 33-70.

[13] Impact of palm, mustard, waste cooking oil and calophyllum inophyllum biofuels on performance and emission of ci engine / A. Sanjid, H.H. Masjuki, M.A. Kalam, [et al.] // Renewable and Sustainable Energy Reviews. 2013. T. 27. C. 664-682.

[14] Bioremediation strategies for diesel and biodiesel in oxisol from southern brazil / D.D. Meyer, S.A. Beker, F. Bücker [et al.] // International Biodeterioration & Biodegradation. 2014. T. 95. C. 356-363.

[15] Likhanov V.A., Lopatin O.P. Use of Natural Gas, Methanol, and Ethanol Fuel Emulsions as Environmentally Friendly Energy Carriers for Mobile Heat Power Plants // Thermal Engineering. 2017. Vol.64. No. 12. P. 935-944.