Integrated diesel engine toxicity reduction system

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Abstract. The issues of natural gas application and recirculation as a complex method of reducing the toxicity of diesel exhaust gases are considered. The results of experimental studies on the influence of natural gas and recirculation on the effective characteristics, toxicity and smokiness of exhaust gases are presented. At the same time, special attention is paid to power and economic characteristics, indicators of the combustion process, toxicity and smokiness of exhaust gases. The presented results of experimental studies prove the effectiveness of the application as a comprehensive system of reducing the toxicity of diesel engine natural gas and exhaust gas recirculation.

Currently, among all types of transport, the problem of increasing the environmental purity of exhaust gases (EG) is most acute for mobile agricultural machinery. The increasing relevance of this problem for tractors and other agricultural machinery equipped with diesel engines is due to the existing and planned to introduce regulations for the control of emissions of toxic components of EG [1-3].

At the present stage of development of science and technology diesel engine for most tractors and agricultural machinery remains almost the main type of drive. The steady increase in the consumption of oil fuel by agricultural machinery and the constant tightening of environmental requirements to it compels mankind to look for alternative energy sources, since their use should reduce the environmental damage caused to the environment as a result of the use of oil fuels [4-6]. At the same time, the share of alternative fuels in the total balance of consumption of motor oil fuels is insignificant. However, due to the worsening energy crisis, the growing shortage of oil energy carriers and the need to solve acute environmental problems in the near future, we should expect to expand the use of alternative motor fuels [7-9].

The EG of tractor diesel engines running on oil fuel contain more than 200 toxic components. One of the most harmful are nitrogen oxides and particulate matter, consisting mainly of soot. Of the variety of existing methods to reduce the toxicity of EG, the greatest effect is achieved by the use of alternative fuels that are less prone to the formation of soot in the combustion chamber due to the characteristics of the chemical composition and less physical properties. Such fuels, first of all, include natural gas [10-12].

In the Vyatka State Agricultural Academy, the department of heat engines, cars and tractors conducted research on the transfer of a tractor diesel engine 4F 11.0/12.5 (D-240) to work on natural gas with EG recirculation (EGR). In order to determine and optimize the main parameters of the
tractor diesel engine when operating on natural gas with EGR, its bench tests on diesel, gas-diesel and gas-diesel with EGR processes were carried out. It was found that the tractor gas-diesel engine is stable at the following ratios: natural gas - 80%, ignition portion of diesel fuel - 20%. Studies of the working process of the tractor gas-diesel engine were carried out at the specified ratio [13-15].

The adjusting characteristics, depending on the change in the setting angle of the fuel injection advance during the operation of the tractor diesel engine by diesel, gas-diesel and gas-diesel with EGR processes at the nominal speed (n=2200 min\(^{-1}\)) and the speed at the maximum torque (n=1700 min\(^{-1}\)) for effective indicators, are shown in figure 1.

![Figure 1. Effective performance of the tractor gas-diesel engine 4F 11.0/12.5 depending on the change \(\Theta_{\text{inj}}\).](image)

![Figure 2. Indicators of the combustion process of a tractor gas-diesel engine 4F 11.0/12.5, depending on the change \(\Theta_{\text{inj}}\) at n=2200 min\(^{-1}\).](image)

The characteristics were removed to determine the optimal value of the control angle of fuel injection for the gas-diesel process when working with EGR for equal values of effective pressures. It follows from figure 1 that when working on the gas-diesel process with cooled EGR, the setting angle of the fuel injection advance at \(n = 2200 \text{ min}^{-1}\) under the condition of the best efficiency is \(\Theta_{\text{inj}} = 23\) deg. The hourly fuel consumption for the gas-diesel process at the optimum setting angle of fuel injection is 11.41 kg/h, and for the gas-diesel process with EGR 10% - 11.73 kg/h. The specific effective fuel consumption at the optimum angle for the gas-diesel process is 205 g/kW·h, and at the gas-diesel process with EGR 10% - 211 g/kW·h.

At a fuel injection angle of 26° at the gas-diesel process with EGR, the specific fuel consumption is increased, the power of the tractor gas-diesel engine remains at the same level. If the angle is 20°, the specific fuel consumption increases, as well as the power of the gas-diesel engine decreases. At the maximum torque speed and under the same conditions, the optimum fuel injection advance angle in the gas-diesel process from the EGR will be 23° to the top point. When working on gas-diesel process with the EGR at an angle \(\Theta_{\text{inj}} = 26\)° and the rotation speed \(n = 2200 \text{ min}^{-1}\) at the conditions to ensure the quality of the combustion process there is a need to reduce the angle of installation of an advancing of injection of fuel due to the increase in maximum pressure and stiffness of the combustion process in relation to 23°.
Figure 2 shows the combustion process of a gas-diesel engine depending on the change in the setting angle of the fuel injection advance for the nominal speed \( n = 2200 \, \text{min}^{-1} \).

From figure 2 it is seen that when working on gas-diesel process with the EGR reduces the maximum gas pressure in the cylinder and when \( \Theta_{\text{inj}} = 26^\circ \) when working with EGR 10% is 9.7 MPa. The rigidity of the combustion process decreases, and at \( \Theta_{\text{inj}} = 26^\circ \) when working with EGR 10% value \((dp/d\phi)_{\text{max}}\) is 0.95 MPa/deg. The angle corresponding to the ignition delay period increases slightly. At the setting angle of advance of fuel injection 23°, the maximum pressure in the cylinder of the tractor gas-diesel engine at the gas-diesel process is 8.5 MPa, and at the gas-diesel process with EGR 10% - 8.2 MPa. The rigidity of the combustion process at the setting angle of the fuel injection 23° at the gas-diesel process with EGR 10% is 0.60 MPa/deg.

The decrease in the combustion process and heat dissipation characteristics when operating on natural gas with EGR at all the studied angles is primarily due to the limitation of the excess air ratio, which leads to an increase in the angle corresponding to the ignition delay period, that is, the combustion process takes place for a shorter period of time and less intensively, which in turn prevents the oxidation of nitrogen of the methane-air mixture under conditions of lack of oxygen, slows down the formation of nitrogen oxides in the cylinder and, accordingly, reduces the content of nitrogen oxides in the EG of the gas-diesel engine [16-19].

The content of toxic components in the EG of the gas-diesel engine depending on the change in the installation angle of the fuel injection advance for the speed \( n = 2200 \, \text{min}^{-1} \) is shown in figure 3.

![Figure 3](image-url) **Figure 3.** The content of toxic components in the EG of a gas-diesel engine of the engine 4F 11.0/12.5, depending on the change in the installation advance angle of fuel injection at \( n = 2200 \, \text{min}^{-1} \).

From figure 3 it is seen that when you change the angle of installation of an advancing of injection of fuel oxides of nitrogen when operating on methane-diesel with EGR process varies, depending on the diesel the same process, i.e. increasing the angle output of nitrogen oxides increases. Thus, during operation of the diesel engine with EGR 10% at \( \Theta_{\text{inj}} = 26^\circ \) the content of NO\(_x\) in the EG is 0.13%, which is below the 21.2% gas diesel process and below 3.7% of the diesel process. When operating a
A diesel engine with an EGR of 10% at $\Theta_{\text{inj}} = 23^\circ$, the $\text{NO}_x$ content in the EG is 0.11%, which is 24.1% lower than the gas-diesel process and corresponds to the diesel process. A further increase in the degree of EGR leads to an even greater decrease in the content of nitrogen oxides, but causes an increase in incomplete combustion products. The gas-diesel process is accompanied by an increase in emissions of total hydrocarbons - their content in EG is 4-5 times higher than in the diesel process. The concentration of $\text{CH}_4$, depending on the setting angle of advance of fuel injection during the gas-diesel process with and without EGR decreases with increasing the angle of advance of fuel injection. During operation of the diesel engine with EGR 10% $\Theta_{\text{inj}} = 26^\circ$, the $\text{CH}_4$ content was 0.32%, below the 5.9% compared to the gas-diesel process. When operating a gas diesel engine with an EGR of 10% at $\Theta_{\text{inj}} = 23^\circ$, the $\text{CH}_4$ content is 0.36%, which is 9.9% lower compared to the gas-diesel process. The use of EGR 20% leads to an increase in the content of $\text{CH}_4$ to higher values than in the pure gas-diesel process.

Analysis of the soot content in the EG during the work on the gas-diesel process with and without EGR shows that with an increase in the fuel injection advance angle, the soot content practically does not increase. The use of EGR leads to a slight increase in the soot content, while the diesel process significantly increases the soot content. The fluidity of EG in the gas-diesel process with and without EGR is 4-5 times lower than the diesel process. The content of CO with increasing angle when working on the gas-diesel process with EGR also decreases.

When working on the gas-diesel process with EGR 10% at $\Theta_{\text{inj}} = 23^\circ$ CO content in the EG is higher by 6.3% of the gas-diesel process, lower by 25.6% of the diesel process. The $\text{CO}_2$ content decreases with increasing angle when working with the EGR gas-diesel process, and with increasing EGR the decrease occurs to a greater extent. Thus, during operation of the diesel engine with EGR 10% $\Theta_{\text{inj}} = 23^\circ$ the $\text{CO}_2$ content in the EG is higher by 5.1% gas diesel process, lower by 45.4% of the diesel process.

Thus, according to the results of the adjustment characteristics, depending on the change in the installation angle of the fuel injection advance, its influence on the power and economic indicators, on the content of toxic components in the EG and the content of nitrogen oxides in the cylinder, the parameters of the combustion process and heat release, at speeds of $n = 2200 \text{ min}^{-1}$ and $n = 1700 \text{ min}^{-1}$, the installation angle of the fuel injection advance $23^\circ$ to the upper dead point was chosen as optimal for the gas-diesel process with EGR. Since the tractor gas-diesel engine does not have any device for rapid change of the installation angle, the same value is recommended for the diesel process.

The content of toxic components in the EG of the gas diesel, depending on the change in load at a speed of $n = 2200 \text{ min}^{-1}$ and the setting angle of advance of fuel injection $23^\circ$, is shown in figure 4.

Figure 4 shows that the use of natural gas in a tractor diesel engine leads to an increase in the content of nitrogen oxides in the EG. Thus, at the nominal operating mode, this increase is 24.1%, and at $p_v = 0.13 \text{ MPa}$, the emission of nitrogen oxides increases by 60.5%. The use of EGR reduces the content of nitrogen oxides in them over the entire range of load changes. When working on the gas-diesel process with EGR 40% in the range of load changes from 0.13 to 0.26 MPa, the $\text{NO}_x$ content is reduced by 63.4%.

When operating gas diesel in nominal mode with EGR 10% $\text{NO}_x$ content in the EG is lower by 24.1% than in the gas-diesel process, and corresponds to the diesel process. The use of EGR causes an ambiguous effect on the total hydrocarbon content. Thus, when working with EGR gas diesel 40% at low loads from 0.13 to 0.26 MPa is a decrease in $\text{CH}_4$ 8.7-14.5%, but at $p_v = 0.51 \text{ MPa}$, on the contrary, an increase of 42.5%.

When operating in nominal mode with EGR 10%, the content of $\text{CH}_4$ is reduced by 9.9%, and with an increase in the degree of EGR to 20%, the emission of $\text{CH}_4$ with EGR increases by 10.2%. The content of soot in the EG is significantly reduced when working on the gas-diesel process. During operation of the diesel engine with EGR 40% at low loads the increase in the content of carbon black is not more than 5%. When operating in the nominal mode with EGR 10%, there is an increase in soot emissions by 4.1%, with $p = 20\%$ - by 12.5%. The use of EGR on gas diesel leads to an increase in the content of CO and $\text{CO}_2$ in the entire range of load changes. Thus, when working with EGR 40% at
medium loads from 0.26 to 0.38 MPa, the content of CO and CO\textsubscript{2} increases from 12.3 to 17.1% and from 42.2 to 48.8%, respectively. When working with EGR 20% at rated load, the increase is 18.9% and 20.0%, while reducing EGR to 10% increase is 6.3% and 5.1% for CO and CO\textsubscript{2} respectively. It should be noted that a significant increase in total hydrocarbons at high loads is due to incomplete combustion of fuel in conditions of lack of oxidizer with an increase in the degree of EGR.

Based on the consideration of the current state of the problem of toxicity, ways to reduce toxicity, carried out theoretical and experimental studies, the decision to improve the environmental performance of the tractor diesel engine using natural gas with EGR.

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