Indicators of the processes of combustion and soot content in the cylinder of a car diesel engine of 4CH 11,0/12,5 when working on an alcohol-fuel emulsion

V A Likhanov, A V Rossokhin and R R Devetyarov

Department of thermal engines, automobiles and tractors, Vyatka State Agricultural Academy, October prospect, 133, Kirov, 610017, Russian Federation

E-mail Rossokhin.dvs@mail.ru

Abstract. The paper presents the results of the influence of the use of ethanol-fuel emulsion as a fuel on the performance of the combustion process and the soot formation processes of a 4CH 11,0/12,5 automotive diesel engine with a combustion chamber of the CNIDI type. The influence of the installation angle of advance of fuel injection on the maximum pressure and maximum temperature of the gases in the cylinder, as well as the mass concentration of soot particles in the nominal operating mode, is considered. Alternative fuel has a great influence on the content of soot particles in the combustion products, and their quantity, in turn, has a significant effect on the emissivity of the flame. And the thermal tension of the details of the cylinder-piston group depends on these indicators.

1. Introduction

A strong effect on the emissivity of a flame is exerted by the amount of soot particles per unit volume. When calculating the determination of the number $N$ of soot particles per unit volume of a cylinder of a diesel engine 4CH 11,0/12,5, we made the following assumptions:

- the polydisperse system of soot particles is represented as monodisperse with an equivalent modal particle radius of 20 nm;
- the density of soot particles is independent of the formation mechanism and is 1.9 g/cm$^3$.

Figure 1 shows the change in the indicators of the combustion process and the soot content in the cylinder and the exhaust gas of a 4CH 11,0/12,5 diesel engine when operating on diesel fuel and electric power, depending on the installation of the high voltage circuit in the nominal mode ($n = 2200 \text{ min}^{-1}, p_c = 0.64 \text{ MPa}$) [1, 2].

For a comprehensive assessment of the impact of the use of ETE on the performance of the combustion process and the soot content in the cylinder and the exhaust gas of a diesel engine, we consider the studied parameters at different values of the installation of the UOVТ for both types of fuel. When working on diesel fuel and the value of the installation $\Theta_{\text{ovt}} = 20^\circ$ to TDC, the maximum value of the average temperature of the cycle $T_{\text{max}}$ is 2076 K, the maximum value of the gas pressure in the cylinder $p_{\text{zmax}}$ is 7.9 MPa. Estimated mass concentration of soot in the cylinder at the moment of opening the exhaust valve. Calculation 0,203 g/m$^3$ ($\varphi_{\text{sign}} = 124,0^\circ$ a.s. after TDC), the estimated number
of soot particles in a unit volume of the diesel cylinder at the time of opening of the exhaust valve \( N_{\text{out}} \frac{dt}{dt} \text{calc} = 3,181 \times 10^6 \text{ mm}^{-3} \). The mass concentration of soot at the time of opening the exhaust valve, obtained experimentally, \( C_{\text{out exp}} = 0.223 \text{ g/m}^3 \) [3, 4].

When working on diesel fuel and the value of the installation \( \Theta_{\text{vpr dt}} = 23^\circ \) to TDC, the maximum value of the averaged cycle temperature \( T_{\text{max}} \) is 2115 K, the maximum value of the combustion pressure \( p_{z \text{ max}} \) is 8,4 MPa. Estimated mass concentration of soot in the cylinder at the time of opening the exhaust valve \( C_{\text{out calc}} = 0,146 \text{ g/m}^3 \), the estimated number of soot particles in a unit volume in the cylinder of the diesel at the time of opening of the exhaust valve \( N_{\text{out calc}} = 2,291 \times 10^6 \text{ mm}^{-3} \). The mass concentration of soot obtained experimentally, its experiment is 0,155 g/m³ [5, 6, 7, 8].

2. Experimental part
An increase in the installation UOV to \( \Theta_{\text{vpr dt}} = 26^\circ \) to TDC leads to an increase in the indicators of the combustion process and carbon black in the cylinder and the exhaust gas of the diesel engine. When working in this mode, the temperature \( T_{\text{max}} = 2199 \text{ K} \), the combustion pressure \( p_{z \text{ max}} = 9,0 \text{ MPa} \). The calculations show that the calculated mass concentration of soot in the cylinder at the time of opening the exhaust valve \( C_{\text{out calc}} = 0,153 \text{ g/m}^3 \), the estimated number of soot particles in a unit volume of the cylinder \( N_{\text{out calc}} = 2,405 \times 10^6 \text{ mm}^{-3} \) (\( \varphi_{\text{St}} = 124,0^\circ \text{ p.k.v. after TDC} \)). The mass concentration of soot obtained experimentally, \( C_{\text{out exp}} = 0,163 \text{ g/m}^3 \) [9, 10, 11].

When the value of the installation UOV \( \Theta_{\text{vpr dt}} = 29^\circ \) to TDC is the maximum value of the averaged temperature of the cycle \( T_{\text{max}} = 2240 \text{ K} \), the maximum value of the combustion pressure \( p_{z \text{ max}} = 9,5 \text{ MPa} \). The calculated value of the mass concentration of carbon black in the cylinder at the moment of opening the exhaust valve increases to \( C_{\text{out calc}} = 0,174 \text{ g/m}^3 \), the calculated number of soot particles per unit volume in the cylinder of the diesel increases to \( N_{\text{out calc}} = 2,736 \times 10^6 \text{ mm}^{-3} \). The mass concentration of soot at the time of opening the exhaust valve, obtained experimentally, \( C_{\text{out exp}} = 0,187 \text{ g/m}^3 \) [12, 13, 14].

![Figure 1](image-url) - Change in the indicators of the combustion process and the soot content in the cylinder and exhaust gas of a 4CH 11,0/12,5 diesel engine when operating on diesel fuel and electrical energy, depending on the installation of the UOV: n = 2200 min⁻¹, \( p_c = 0,64 \text{ MPa} \); - - DT; - - - ETE.
When the diesel engine runs on the electric power station at the nominal mode and the installation value of the high-voltage switch \( \Theta_{\text{vpr}} = 20^\circ \) to TDC, the maximum value of the average cycle temperature \( T_{\text{max}} = 2426 \) K, the maximum gas pressure in the cylinder \( p_z\text{max} = 8,26 \) MPa. The calculated mass concentration of carbon black in the cylinder at the moment of opening the exhaust valve of \( C_{\text{out calc}} \) has a value of 0,047 g/m\(^3\) \((\varphi_{\text{exp}} = 124,0^\circ \) p.h. after TDC), the estimated number of soot particles in a unit volume of the cylinder \( N_{\text{out calc}} = 0,745 \times 10^6 \text{ mm}^3 \). The mass concentration of soot at the time of opening the exhaust valve, obtained experimentally, its experience is 0,052 g/m\(^3\) \([15, 16, 17]\).

The analysis of the graphs shows that in the case of an increase in the installation UOVT to \( \Theta_{\text{vpr ete}} = 23^\circ \) to TDC, the maximum value of the average temperature of the cycle is \( T_{\text{max}} = 2511 \) K, the maximum value of gas pressure in the cylinder is \( p_z\text{max} = 8,9 \) MPa. The calculated mass concentration of soot in the cylinder at the time of opening the exhaust valve 0,043 g/m\(^3\), the estimated number of soot particles in a unit volume of the cylinder \( N_{\text{out calc}} = 0,675 \times 10^6 \text{ mm}^3 \). The mass concentration of soot at the time of opening the exhaust valve, obtained experimentally, its experience is 0,047 g/m\(^3\) \([18, 19, 20, 21]\).

An increase in the installation of the UOVT to \( \Theta_{\text{vpr ete}} \geq 26^\circ \) to TDC leads to an increase in the indicators of the combustion process and the soot content in the cylinder and the exhaust gas of the diesel engine. When working in this mode, the maximum value of the average temperature of the cycle \( T_{\text{max}} = 2575 \) K, the maximum value of the combustion pressure \( p_z\text{max} = 9,6 \) MPa. The mass concentration of soot in the cylinder at the time of opening the exhaust valve \( C_{\text{out calc}} = 0,057 \text{ g/m}^3 \), the estimated number of soot particles in a unit volume in the cylinder of the diesel engine at the time of opening the exhaust valve \( N_{\text{out calc}} = 0,892 \times 10^6 \text{ mm}^3 \). The value of the mass concentration of soot obtained experimentally, \( C_{\text{out exp}} \), is 0,063 g/m\(^3\) \([22, 23, 24, 25]\).

With the value of the installation UOVT \( \Theta_{\text{vpr ete}} = 29^\circ \) to TDC, the maximum temperature \( T_{\text{max}} = 2635 \) K, and the maximum gas pressure \( p_z\text{max} = 10,0 \) MPa. The calculated value of the mass concentration of soot in the cylinder at the moment of opening the exhaust valve increases to its own calculation 0,128 g/m\(^3\), the estimated number of soot particles per unit volume of the cylinder of the diesel increases to the new calculation 2,002 \times 10^6 \text{ mm}^3. In this case, the mass concentration of soot at the time of opening the exhaust valve, obtained experimentally, its own experiment 0,133 g/m\(^3\) \([26, 27, 28, 29]\).

Analyzing the studied parameters when working on a DT at the nominal mode \((n = 2200 \text{ min}^{-1}, p_c = 0,64 \text{ MPa})\), we can note the following. At a constant value of the hourly fuel consumption \( G_T \text{ dt} = 13,4 \text{ kg/h} \) and the value of the installation UOVT \( \Theta_{\text{vpr dt}} = 20^\circ \) to TDC, the effective power of \( N_c \) is 53,8 kW, the value of the specific effective consumption of DT \( g_{\text{edt}} \) is 249 g/(kWh). When the value of the installation UOVT increases to \( \Theta_{\text{vpr dt}} = 23^\circ \) to VMT, the effective power of \( N_c \) increases to 55,8 kW, and the value of the specific effective flow of DT \( g_{\text{e dt}} \) decreases to 240 g/(kWh). When the value of the installation UOVT \( \Theta_{\text{vpr dt}} = 26^\circ \) to TDC, the effective power of \( N_c \) is reduced to 55,0 kW, and the value of the specific effective flow of DT \( g_{\text{e dt}} \) is increased to 244 g/(kWh). With a further increase in the installation UOVT \( \Theta_{\text{vpr dt}} = 29^\circ \) to TDC, there is a decrease in the effective power to \( N_c = 53,6 \) kW and an increase in the specific effective flow of DT to \( g_{\text{e dt}} = 250 \) g/(kWh).

From the graphs, it can be seen that when the diesel engine is running at nominal mode on the DT, the effective power reaches a maximum value of \( N_c = 55,8 \) kW at the value of the installation UOVT \( \Theta_{\text{vpr dt}} = 23^\circ \) to TDC. The value of the specific effective flow rate of DT is minimal and is \( g_{\text{e dt}} = 240 \text{ g/(kWh)} \).

Consider the effective performance of a 4CH 11,0/12,5 diesel engine when operating in nominal mode \((n = 2200 \text{ min}^{-1}, p_c = 0,64 \text{ MPa})\) on an ETE. When the value of the setting UOVT \( \Theta_{\text{vpr ete}} = 20^\circ \) to TDC, the constant value of the hourly fuel consumption \( G_{\text{etr}} \) is 16,3 kg/h and the value of the hourly fuel consumption in the composition of the emulsion \( G_{\text{etp priv}} = 11,0 \text{ kg/h} \) the effective power of the \( N_c \) is 55,1 kW. The specific effective fuel consumption of \( g_{\text{e ete}} \) is 296 g/(kWh), the specific effective consumption of DT in the composition of the \( g_{\text{e dt}} \) emulsion it is 200 g/(kWh). When increasing the value of the installation UOVT \( \Theta_{\text{vpr ete}} = 23^\circ \) to TDC, the effective power of \( N_c \) increases to 55,8 kW, the value of the specific effective fuel consumption of \( g_{\text{e ete}} \) decreases to 292 g/(kWh), the value of the specific
effective consumption of DT in the composition of the ge dt emulsion. reduced to 197 g/(kWh). If the value of the setting UOVT Θvpr ete = 26° effective power Ne is reduced to 54,4 kW, the value of specific effective fuel consumption ge ete increases to 300 g/(kWh), the value of the effective specific consumption of diesel fuel in the emulsion ge dt increases to 202 g/(kWh). With a further increase in the installation UOVT Θvpr ete = 29° to TDC, the effective power is reduced to Ne = 52,0 kW, the specific effective fuel consumption is increased to ge ete = 313 g/(kWh), and the specific effective consumption of DT in the emulsion is increased to ge dt priv = 212 g/(kWh).

From the graphs, it follows that when working on ETE, the effective power reaches the maximum value of Ne = 55,8 kW with the value of the installation UOVT Θvpr dt = 23° to TDC. The value of the specific effective flow of DT in the ETE is minimal and is ge dt priv = 197 g/(kWh). When the diesel engine is running on ETE, there is an increase in the values of GT and ge for all the values of the installation UOVT. This is due to the lower calorific value of ETE compared to DT.

Analyzing the effective performance when working on a DT at a speed corresponding to the maximum torque mode (n = 1700 min⁻¹), we can note the following. At a constant value of the hourly fuel consumption GT dt = 10,5 kg/h and the value of the installation UOVT Θvpr dt = 20° to TDC, the effective power of Ne is 45,9 kW, the value of the specific effective consumption of DT ge dt = 229 g/(kWh). When the value of the installation UOVT increases to Θvpr dt = 23° to VMT, the effective power of Ne increases to 46,2 kW, and the value of the specific effective flow of DT ge dt = 227 g/(kWh). When the value of the installation UOVT Θvpr dt = 26° to VMT, the effective power of Ne is reduced to 45,6 kW, and the value of the specific effective flow of DT ge dt is increased to 230 g/(kWh). An increase in the installation UWT to Θvpr dt = 29° to TDC leads to a decrease in the effective power to Ne = 43,9 kW and an increase in the specific effective flow of DT to ge dt = 239 g/(kWh).

3. Conclusion
Analyzing the dependencies corresponding to the operation of the diesel engine in the nominal mode, the following can be noted. In the transition from diesel fuel to alternative fuel ETE for all values of the installation of high-voltage fuel cells, a significant decrease in the calculated and experimental values of the carbon black content at the time of opening of the exhaust valve is observed. The minimum values of the carbon black content when working on diesel fuel and ETE are achieved with a value of the installation UOVT Θvpr = 23° to TDC [30, 31, 32, 33].

References
[1] Mohammadi Khoshkar Vandani A and Joda F 2016 Energy Conversion and Management 109 103-12
[2] Dincer I and Zamfirescu C 2016 Journal of Natural Gas Science and Engineering 28 461-78
[3] Anisimov I, Ivanov A, Chikishev E, Chainikov D, Reznik L and Gavaev A 2017 International Journal of Sustainable Development and Planning 12 1006-17
[4] Likhanov V A and Lopatin O P 2019 Journal of Physics: Conf. Series 1399 055016
[5] Arent D J, Wise A and Gelman R 2011 Energy Economics 33 584-93
[6] Chang W R, Hwang J J and Wu W 2017 Renewable and Sustainable Energy Reviews 67 277-88
[7] Likhanov V A and Lopatin O P 2019 Journal of Physics: Conf. Series 1399 055020
[8] Likhanov V A, Lopatin O P and Yurlov A S 2019 Journal of Physics: Conf. Series 1399 055026
[9] Aydin F and Ogut H 2017 Renewable Energy 103 688-94
[10] Lif A and Holmberg K 2006 Advances in Colloid and Interface Science 123 231-39
[11] Luksho V A, Kozlov A V, Terenchenko A S and Grinev V N 2018 International Journal of Mechanical Engineering and Technology 9 1385-95
[12] Likhanov V A and Lopatin O P 2017 Thermal Engineering 64(12) 935-44
[13] Sivakumar M, Ramesh kumar R, Syed Thastagir M H and Shanmuga Sundaram N 2018 Renewable Energy 116 518-26
[14] Yadava S and Maitra S S 2017 Global Nest Journal 19 533-9
[15] Ahmad I 2016 Journal of Pure and Applied Microbiology 10 95-102
[16] Likhanov V A and Lopatin O P 2019 *Ecology and Industry of Russia* **23(9)** 60-5
[17] Shatrov M G, Sinyavski V V, Dunin A Y, Shishlov I G, Vakulenko A V and Yakovenko A L 2018 *International Journal of Engineering and Technology* **7** 288-95
[18] Zhilenkov A A and Efremov A A 2017 *IOP Conference Series: Materials Science and Engineering* **10** 012043
[19] Chen W, Pan J, Liu Y, Fan B, Liu H and Otchere P 2019 *Applied Energy* **176** 453-67
[20] Semprini S, Sánchez D and De Pascale A 2016 *Solar Energy* **132** 279-93
[21] Osorio-Tejada J L, Llera-Sastresa E and Scarpellini S 2017 *Renewable and Sustainable Energy Reviews* **71** 785-95
[22] Likhanov V A and Rossokhin A V 2018 *IOP Conference Series: Materials Science and Engineering* **457**(1) 012007
[23] Likhanov V A and Skryabin M L 2019 *IOP Conference Series: Earth and Environmental Science* **315** 032045
[24] Likhanov V A and Rossokhin A V 2019 *Journal of Physics: Conference Series* **1399**(4) 044038
[25] Jeevahan J, Mageshwaran G, Joseph G B, Raj R B D and Kannan R T 2017 *Chemical Engineering Communications* **204** 1202-23
[26] Likhanov V A and Rossokhin A V 2020 *IOP Conference Series: Materials Science and Engineering* **734** 012207
[27] Frances C 2009 *Sustainability* **1** 43-54
[28] Sinyavski V V, Shatrov M G, Dunin A Y, Shishlov I G and Vakulenko A V 2019 *Periodicals of Engineering and Natural Sciences* **7** 281-6
[29] Likhanov V A, Kozlov A N and Araslanov M I 2020 *IOP Conference Series: Materials Science and Engineering* **734** 012211
[30] Kozlov A N, Anfilatov A A and Chuvashov A N 2019 *Journal of Physics: Conference Series* **1399** 055051
[31] Skryabin M L 2020 *IOP Conference Series: Earth and Environmental Science* **421** 072012
[32] Chuvashov A N, Chuprakov A I and Anfilatov A A 2020 *IOP Conference Series: Materials Science and Engineering* **734** 012184
[33] Skryabin M L and Likhanov V A 2019 *Journal of Physics: Conference Series* **1399** 044063