Analysis of the combustion process of diesel fuel in the cylinder 2F 10.5 / 12.0 depending on the frequency of rotation of the crankshaft

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Abstract. Stable operation of the diesel engine at all speeds is provided by the adjustment of the fuel equipment, the structural parameters of the combustion chamber, the physical and chemical properties of the fuel, etc. To increase the range of operating speeds of the engine and increase its injectivity, studies are being conducted aimed at optimizing the processes of fuel combustion, improving the adjustments of the fuel equipment, shape and size of the combustion chamber. This paper presents an analysis of the performance of the diesel fuel combustion process in a 2F 10.5/12.0 diesel cylinder at rated load at various speed modes of operation with a fixed mechanism for controlling the cycle fuel supply. When conducting a laboratory study, measurements were made of hourly fuel and air consumption in all modes of operation. The diesel was installed on a loading stand with a weight mechanism, with which the torque measurement was carried out. The results of indexing the working process of the diesel engine, the characteristics of heat. Calculation of heat release rate and gas temperature indicator was carried out by the CNIDI method.

1. Introduction
Piston internal combustion engines are one of the main sources of energy at present. According to the set of properties, they meet the requirements for them, and in the near future, they are not expected to be replaced by other, fundamentally different energy sources. However, the steady increase in the number of internal combustion engines has led to the fact that at the moment automotive diesel engines are one of the main sources of toxic emissions into the atmosphere. Thus, the improvement of economic as well as environmental performance is a priority for the improvement and development of reciprocating internal combustion engines. Deep and consistent analysis of the combustion process in a diesel engine at different load and speed modes of operation is necessary to accumulate and refine knowledge of the combustion process and heat generation in the cylinder, which is of particular value in determining the optimal adjustments to the fuel supply equipment, designing the combustion chamber of a modern diesel engine, and forming requirements for physical-chemical properties of fuel [1]-[6].

2. Materials and methods
In the Vyatka State Agricultural Academy, the Department of Heat Engines, Automobiles and Tractors conducted research on the work of a tractor diesel engine under various operating conditions.
Part of this research was bench testing of a tractor diesel 2F 10.5 / 12.0 with a hemispherical combustion chamber in a piston, a characteristic of which is presented in Table 1.

Table 1. Main diesel engine characteristics and operating mode parameters.

|                  | Diesel 2F 10.5/12.0 |
|------------------|----------------------|
| Diesel type      | Air cooling with the hemispherical combustion chamber |
| Number of cylinders | 2                   |
| Working volume   | 2080 cm$^3$          |
| Nominal frequency of crankshaft rotation | 1800 rpm |
| Piston diameter  | 105 mm               |
| Piston stroke    | 120 mm               |
| Compression ratio | 16.5                |
| The installation angle of the injection of fuel | 30 deg bTDC |
| Rated power      | 18.4 kW              |
| Mean effective pressure | 0.588 MPa |
| Specific effective fuel consumption | 241.8 g/kW*h |

Diesel 2F 10.5/12.0 refers to the engines of land transport, for which the speed characteristic is the main. The speed characteristic was removed with a fixed control lever of the high-pressure fuel pump to eliminate the correction of the cyclic fuel supply by the all-mode regulator. The cyclic fuel supply was fixed at the nominal mode of diesel operation (\( p_e = 0.588 \) MPa and \( n = 1800 \) rpm). The installation advance angle of fuel injection did not change and was equal to 30 deg bTDC.

Figure 1. Signals from pressure sensors and TDS.
The diesel engine workflow was indicated by a PS-01 piezo-quartz pressure sensor, after which the signal from the sensor went to the AQ05-A.1.001 amplifier and the amplified signal went to the personal computer via the LA-2 USB analog-digital converter (figure 1). The array of data obtained as a result of indexing was processed in Matlab.

During the tests, all the necessary parameters were measured: fuel consumption, mass air consumption, diesel load, etc. Measurement of the mass air flow rate was carried out using the gas flow meter RG–250, installed in front of the intake manifold of the diesel engine, and electronic digital tachometer TEMP–4. Measurement of fuel consumption was carried out by an electronic fuel flow meter AIR–50. At the same time, the gas analysis system controlled the composition of the exhaust gases and the content of soot in them [8].

The calculation of the indicator temperature of gases in the cylinder and the rate of heat generation, the rate of heat removal was carried out according to the CNIDI method. The initial data for the calculation is the energy characteristics, fuel consumption, and air excess factor. The diagram of the laboratory setup is shown in figure 2.

![Figure 2](image)

**Figure 2.** Scheme of laboratory installation: 1-diesel 2F10.5/12.0; 2- weight mechanism Rapido; 3- electric balancing machine SAK-N-670; 4-personal computer; 5 LA-2 analog-to-digital converter; 6- electronic fuel flow meter AIR-50; 7-fuel tank; 8- Gas analysis system ASGA-T 9- smoke meter; 10-speed sensor KV; 11 TDC sensor; 12-cylinder pressure sensor PS-01; 13-fuel pressure sensor TDT; 14- high pressure fuel pump; 15- RG-250 air flow meter; 16- ExG temperature sensor; 17- receiver.

### 3. Results

As a result of bench tests, we have obtained the dependence of the main indicators of the engine on the speed of the crankshaft - speed characteristic. Figure 3 shows the dependence of the effective indicators on the speed of the crankshaft of the diesel engine 2F 10.5/12.0 it can be noted that the obtained dependences are generally characteristic of most naturally aspirated diesel engines. The filling ratio \( \eta_v \) depends on the gas velocity in the valve throughput and camshaft phases and decreases with increasing speed, but in the low-speed range (1200-1400 rpm), it can be seen to increase slightly with increasing speed, which is due to the discrepancy between actual camshafts phases, optimal for a given speed. The mass flow rate of \( G_A \) air increases with increasing speed. Hourly fuel consumption
$G_F$ decreases with decreasing speed, which is explained by a decrease in the frequency of operating cycles. Engine power increases with increasing speed, this occurs as long as the effect of an increase in crankshaft speed is greater than the effect of reducing the average effective pressure due to an increase in mechanical losses [9].

The analysis of the combined indicator diagrams presented in figure 4 allows us to conclude that with an increase in the rotational frequency, the maximum combustion pressure decreases by 7% from $P_Z = 7.73$ when $n = 1200$ rpm to $P_Z = 7.14$ when $n = 2000$ rpm simultaneously with growth rotational speeds, an increase in the ignition delay period occurs and, as should be expected, a 20% increase in pressure build-up rate with $dp / d\phi = 0.463$ MPa / deg at $n = 1200$ rpm, to $dp / d\phi = 0.56$ MPa / deg at $n = 1600$ rpm.

Figure 3. Effective parameters of diesel depending on the frequency of rotation of a cranked shaft.

Figure 4. Pressure and rate of change of pressure in the cylinder of a diesel engine.
Such an increase in pressure build-up rate is associated with a decrease in the period of time spent on injection, subsequent evaporation and passage of pre-flame reactions in the combustion chamber, as well as a slight increase in the fuel cycle and, accordingly, an increase in the amount of fuel in the combustion chamber of the diesel engine at the time of the start of combustion [10].

The growth of cycle supply at a constant position of the pump control body is explained by the decrease in the effect of fuel leakage through leaks, as well as the increase in the effect of throttling in the suction and inlet windows of the pump at the beginning and end of the discharge [11]. With an increase in the rotation frequency, the averaged temperature of gases in the cylinder decreases; the temperature decreases from 2095 K at \( n = 1200 \) rpm to 1910 K at \( n = 2000 \) rpm. The growth of mass air flow with increasing rotational speed, simultaneously with the reduction of the time spent by the charge in the intake ducts reduces the charge preheating from the diesel engine intake system parts and, accordingly, the charge temperature at the moment of intake decreases.

Analysis of the graphs of the integral characteristics of active heat generation allows us to conclude that at low rotational frequencies (\( n = 1200 \) rpm), part of the heat that enters the cylinder with fuel is lost due to intensive heat exchange with the walls of the combustion chamber, which is a consequence of increased average temperature. At the same time, a part of the charge flows through the leakiness of the piston rings and valve distribution organs, which is caused by an increase in the time the charge is in the volume of the cylinder. The minimum of heat losses and, accordingly, the highest active heat release is observed at a nominal rotation frequency of 1800 rpm. When the diesel engine is operating at different rotational frequencies, the heat loss is 10-14\%. The differential characteristic of heat generation has two pronounced maxima characteristic of high-speed diesel engines, which is in good agreement with the theory of homogeneous and diffusive combustion [12]. With an increase in the crankshaft rotation speed, the rate of heat release increases by 50\% from \( \left( \frac{d\chi}{d\phi} \right)_{\text{max}} = 0.04 \) at \( n = 1200 \) rpm to \( \left( \frac{d\chi}{d\phi} \right)_{\text{max}} = 0.06 \) at \( n = 2000 \) rpm, at the same time a gradual increase in the amount of fuel burning in a homogeneous mixture formed during the ignition delay period, and the proportion of fuel burned in the diffusion phase decreases. The high rate of heat release near the start of combustion is the main reason for the high rate of pressure build-up and associated negative phenomena: high noise level significant dynamic load of bearings and parts of the crank mechanism [13].

When analyzing the characteristics of heat release, it is important to compare the amount of heat release at characteristic points: with maximum pressure in the cylinder, the maximum temperature and at TDS [14]. An increase in the speed leads to an increase in heat dissipation at a maximum pressure of \( \chi_{P_{\text{max}}} = 0.52 \) at 1200 rpm to 0.56 at 2000 rpm. The graph of heat release at the maximum temperature \( \chi_{T_{\text{max}}} \) depending on the speed is a quadratic parabola with an extremum at a frequency of 1600 rpm. Heat dissipation in TDC with increasing speed also increases. The duration of combustion decreases with an increase in rotational speed by 39\% from 12 ms at 1200 rpm to 7.24 ms at 2000 rpm, while the duration of combustion in degrees’ increases [14-24].

4. Conclusions

As a result, the results of processing the high-speed characteristics of a diesel engine operating on diesel fuel with a fixed fuel supply reveal several features of the combustion process:

- An increase of 23\% in the ignition delay period associated with an increase in the rotational speed;
- 39\% reduced duration of combustion, expressed in milliseconds;
- As the rotational speed increases, the volume of fuel that burns in a homogeneous mixture increases by 10\%, the maximum heat release rate increases by 50\%;
- When the rotational speed decreases by 7\%, the maximum combustion pressure increases;
- When the rotational speed decreases by 5\%, the outflow of heat from the working medium increases due to an increase in the maximum temperature by 100 K and the duration of heat exchange.
In order to reduce the effect of the increase in the ignition delay period with the increase in the speed of rotation on this diesel engine, it is recommended to install a mechanism for regulating the injection angle depending on the speed of the diesel crankshaft.

References
[1] Asad U and Zheng M Fast heat release characterization of a diesel engine 2008 *International Journal of Thermal Sciences* **47** 1688-700
[2] Cheng Q, Tuomo H, Tapani O and Larmi Martti K. Spray dynamics of HVO and EN590 diesel fuels 2019 *Fuel* **245** 198-211
[3] Sahin Z, Kurt M and Durgun O. Heat release analysis of gasoline fumigation in a diesel engine 2018 *Energy Procedia* **147** 322-28
[4] Srinidhi C, Madhusudhan A and Channapattana S. V. Effect of NiO nanoparticles on performance and emission characteristics at various injection timings using biodiesel-diesel blends 2019 *Fuel* **235** 185-93
[5] Zhang R, Pham P. X, Kook S and Masri A R Influence of biodiesel carbon chain length on in-cylinder soot processes in a small bore optical diesel engine 2019 *Fuel* **235** 1184-94
[6] Zhang S, Zhao C and Zhao Z. Heat Release Analysis of Hydraulic Free Piston Diesel Engine 2014 *Energy Procedia* **61** 2505-08
[7] Likhanov V A and Lopatin O P 2018 *Ecology and Industry of Russia* 22
[8] Romanyuk V, Likhanov V A and Lopatin O P 2018 *Theoretical and Applied Ecology* 3
[9] Likhanov V A and Lopatin O P 2017 *Thermal Engineering* 64
[10] Likhanov V A and Lopatin O P 2018 *IOP Conference Series: Materials Science and Engineering* **457** 012011
[11] Likhanov V A and Lopatin O P 2019 *Ecology and Industry of Russia* **23**
[12] Marchuk A, Likhanov V A and Lopatin O P 2019 *Theoretical and Applied Ecology* 3
[13] Likhanov V A and Rossokin A V 2018 *IOP Conference Series: Materials Science and Engineering* **457** 012007
[14] Likhanov V A and Skryabin M L 2019 *IOP Conference Series: Earth and Environmental Science* **315** 032045
[15] Yusong Y 2019 *Energy* **186** 115768
[16] Guedes A D M, Braga S L and Pradelle F 2018 *Fuel* **225** 174-83
[17] Smith O J 1981 Fundamentals of Soot Formation in Flames with Application of Diesel Engine particulate Emissions *Progress in Energy and Combustion Science* **7** 275-91
[18] Hemmerlein N, Korte V and Richter H Performance exhaust emissions and durability of modern diesel engines running on rapeseed oil SAE 1991 *Technical Paper Series* 910848
[19] Kittelson D and Kraft M Particle formation and models in internal combustion engines 2014 *Cambridge centre for computational chemical engineering* 39
[20] Klippenstein S, Georgievskii Y and Harding L 2016 Predictive theory for the combination kinetics of two alkyl radicals *Phys. Chem. Chem. Phys.* **8** 1133–47
[21] Wagner, H. Gg Soot formation in combustion 1979 17th Int. Symp. Combust. 3-19
[22] Vyrubov D N, Ivashchenko N A, Ivin V I et al. Internal combustion engine: Theory of piston and combined engines 1983 *Moscow: Mechanical engineering* 372 p
[23] Voinov A N 1977 *Combustion in high-speed piston engines* (Moscow: Mechanical engineering)
[24] Khan I M 1969 Formation and combustion of carbon in a diesel engine *Inst. Mech. Eng. Proc.* **184** 36-43