Natural gas combustion in diesel engine

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Abstract. The article is devoted to the use of natural gas as an alternative fuel for diesel engines. When operating the diesel engine on natural gas with an additional portion of the diesel fuel are distinctive features of the processes of mixture formation and combustion, there is heterogeneity of the combustible mixture in the cylinder, more fuel evaporation and other aspects of the processes of formation of the fuel-air mixture and its combustion. Consequently, the use of alternative fuels with different chemical composition leads to distinctive indicators of the combustion process. Therefore, for the scientific representation of the real picture of the combustion process in a diesel engine running on natural gas, it is necessary to conduct an indication of its working process and a detailed description of the combustion process.

Since the beginning of the development of internal combustion engines, the so-called indicator diagram - the curve of the pressure change in the cylinder of a piston engine during the working cycle - is used as one of the means of describing and analyzing the working process.

One of the valuable qualities of the indicator chart, which has long attracted the attention of researchers, is that it is a direct record of the actual physical quantities, the values of which can be observed without any additional calculations on the chart itself. Indicator diagram gives the possibility to obtain important information about the flow of the workflow. Directly from the indicator diagram you can get data on the value of the maximum combustion acceleration $p_z$, the rate of pressure increase $dp/d\phi$ at different sites, the pressure at the inlet and outlet, the value of the angle $\phi_i$ corresponding to the ignition delay period. Thus, the indicator diagram is one of the effective means of observing the self-ignition in a diesel engine. The useful area of the indicator chart in $p$-$v$ coordinates determines the working pressure inside the cylinder per cycle, and knowing the working cycle it is easy to determine such basic indicators of the working process as the average effective pressure and power [1-3].

The combustion process in a diesel engine running on alternative fuels is even more sensitive in comparison with the regular diesel process to many structural and operational factors. The origin and development of combustion, the completeness of combustion of the fuel-air mixture of alternative fuel are also determined by the characteristics and rates of reactions, the conditions of heat and mass transfer in the flame zone and heat transfer to the cylinder walls. Gorenjeski the rate of propagation of the flame front in the combustion process depends on chemical and physical factors and in combination with the rate of chemical reaction of oxygenation of alternative fuel molecules ultimately affects the duration of combustion of the mass of the working mixture in the combustion chamber of a diesel engine. For example, due to uneven distribution of the tested fuel in the cylinders, the composition of the fuel-air mixture may be close to the concentration limits of flame propagation, in connection with which a possible misfire and combustion in the individual cylinders or combustion process may become slow [4-6].
A distinctive feature of the process of mixture formation in a diesel engine when operating on natural gas (NG) with an additional portion of diesel fuel is characterized by inhomogeneity of the fuel mixture in the cylinder, other evaporation of the fuel and other time of the processes of formation of the fuel-air mixture and its combustion.

The use of alternative fuels with different chemical composition and local conditions may lead to distinctive indicators of the combustion process and even to early ignition. Therefore, for the scientific representation of the actual picture of the combustion process of a diesel engine running on NG, a detailed and sufficiently reliable description of this process is necessary, which can be performed only after the indexing of the working process of the diesel engine [7-9].

The combustion process was investigated using the electro-pneumatic indicator MAI-5A with a pressure sensor mounted in the head 1 of the cylinder. The registration mechanism was installed in front of the engine on the same axis with the crankshaft through an intermediate clutch in accordance with the instructions of MAI-5A. The upper dead center setting (TDC) timer was tested according to the position of the piston in the TDC in the first cylinder and controlled by a compression-expansion schedule without fuel. Processing of indicator diagrams was carried out using the computer program TSNIDI-TSNIM [10-12].

Figure 1 shows the indicator diagrams of the diesel engine at rated speed (n=2200 min⁻¹). Analyzing the indicator diagrams presented in this mode, it is clearly visible the increase in the ignition delay period and the maximum pressure of the pz cycle when working on NG. Thus, at Θ_inj = 23°, the use of NG increases the angle φ_i by 7.5°, while pz increases by 0.4 MPa. At Θ_inj = 26°, this increase is 7.5° and 1.3 MPa for φ_i and p_z respectively [13-15].

![Figure 1](image1.png)

**Figure 1.** The indicator diagram of the diesel engine 4F 11.0/12.5 at n=2200 min⁻¹:

a - Θ_inj=23°; b - Θ_inj=26°.

Figure 2a shows the parameters of the combustion process of a diesel engine depending Θ_inj at n=2200 min⁻¹. Considering the experimental curves of parameters of the combustion process in the cylinder of a diesel engine fuelled with NG, it is necessary to highlight that with the increase Θ_inj increase of maximum cycle pressure p_z, the maximum gas temperature T_max, the degree of pressure
increase \( \lambda \), the rigidity of the combustion process \((dp/d\phi)_{\text{max}}\) and decreases the value of the angle \( \phi_i \) corresponding to the ignition delay period [16-18].

Figure 2b shows the parameters of the combustion process of a diesel engine at a speed of 2200 min\(^{-1}\) at different load modes.

![Figure 2](image)

**Figure 2.** Indicators of the combustion process of diesel engine 4F 11.0/12.5 at \( n=2200 \text{ min}^{-1} \):

- a - from the change \( \Theta_{\text{inj}} \);
- b - from the change load.

Considering the operation of a diesel engine on NG it is clearly seen that with increasing load there is an increase in the maximum average temperature of the gases in the cylinder \( T_{\text{max}} \), the maximum pressure \( p_z \), the degree of pressure increase \( \lambda \), the rigidity of the combustion process \((dp/d\phi)_{\text{max}}\) and a decrease in the angle \( \phi_i \) corresponding to the ignition delay period. For example, when working on NG in the load range from 0.13 to 0.71 MPa \( T_{\text{max}} \) values increase from 1400 to 3560 K, or 2.5 times; \( p_z \) max from 5.2 to 10.4 MPa, or exactly 2 times; \( \lambda \) from 1.2 to 2.5, or 2.1 times; \((dp/d\phi)_{\text{max}}\) from 0.46 to 0.76 MPa/deg, or 65.2% and decrease \( \phi_i \) from 30.5 to 29.5º crankshaft rotation [19, 20].

On the basis of the conducted researches on the nominal operating mode \( \Theta_{\text{inj}}=23^\circ \) application of NG leads to values of parameters of process of combustion of the diesel engine specified in table 1.

| Fuel  | Indicators          |   |   |   |   |
|-------|---------------------|---|---|---|---|
|       | \( T_{\text{max}}, \text{K} \) | \( p_z, \text{MPa} \) | \( \lambda \) | \((dp/d\phi)_{\text{max}}, \text{MPa/deg} \) | \( \phi_i, \text{deg} \) |
| Diesel| 2190 (an)           | 8.1 | 1.90 | 0.59 | 22.5 |
|       | 3010 (an)           | 8.5 (an) | 2.0 (an) | 0.69 (an) | 30.0 (an) |
| NG    | increase of 37.4%   | increase of 4.9% | increase of 5.3% | increase of 17.0% | increase of 33.3% |

Table 1. Results of studies of combustion process parameters diesel engine 4F 11.0/12.5 at \( \Theta_{\text{inj}}=23^\circ \) and rated mode (\( n=2200 \text{ min}^{-1}, \ p_e=0.64 \text{ MPa} \)).

Figure 3 shows the indicator diagrams of the diesel engine at the speed corresponding to the maximum torque (\( n=1700 \text{ min}^{-1} \)). Analyzing the indicator diagrams on the NG at this speed shows an
increase in the ignition delay period and the maximum pressure of the cycle $p_z$. Thus, at $\Theta_{inj}=23^\circ$, the use of NG increases the angle corresponding to the ignition delay period $\phi_i$ by $2.0^\circ$, while $p_z$ increases by 2.4 MPa. At $\Theta_{inj}=26^\circ$, this increase is $2.0^\circ$ and 2.2 MPa for $\phi_i$ and $p_z$ respectively [21, 22].

![Figure 3](image1.png)

**Figure 3.** The indicator diagram of the diesel engine 4F 11.0/12.5 at $n=1700$ min$^{-1}$: a - $\Theta_{inj}=23^\circ$; b - $\Theta_{inj}=26^\circ$.

The results of the study of the combustion characteristics of the diesel engine depending on the $\Theta_{inj}$ at $n=1700$ min$^{-1}$ are shown in figure 4a.

![Figure 4](image2.png)

**Figure 4.** Indicators of the combustion process of diesel engine 4F 11.0/12.5 at $n=1700$ min$^{-1}$: a - from the change $\Theta_{inj}$; b - from the change load.
Considering the curves of the parameters of the NG combustion process, it should be noted that with an increase in $\Theta_{\text{inj}}$ at $n=1700$ min$^{-1}$, the values $T_{\text{max}}$, $p_z$, $\lambda$, $(dp/d\phi)_{\text{max}}$ and the values of the angle $\phi_i$ corresponding to the ignition delay period increase.

Figure 4b shows the parameters of the combustion process of a diesel engine at a speed of 1700 min$^{-1}$ at different load modes. Considering the operation of a diesel engine on NG, it is clearly seen that with increasing load there is an increase in $T_{\text{max}}$, $p_z$, $\lambda$, $(dp/d\phi)_{\text{max}}$ and a decrease in the angle $\phi_i$ corresponding to the ignition delay period.

The results of studies of the characteristics of the combustion process of a diesel engine running on NG at $\Theta_{\text{inj}}=23^\circ$ and $n=1700$ min$^{-1}$ are summarized in table 2.

### Table 2. Results of studies of combustion process parameters diesel engine 4F 11.0/12.5 at $\Theta_{\text{inj}}=23^\circ$ and rated mode ($n=1700$ min$^{-1}$, $p_c=0.69$ MPa).

| Fuel | $T_{\text{max}}$, K | $p_z$, MPa | $\lambda$ | $(dp/d\phi)_{\text{max}}$, MPa/deg | $\phi_i$, deg |
|------|------------------|------------|---------|-------------------------------|------------|
| Diesel | 2210 | 8.6 | 2.0 | 0.64 | 20.0 |
| NG | 3050 (increase of 38.0%) | 11.0 (increase of 27.9%) | 2.60 (increase of 30.0%) | 0.83 (increase of 29.7%) | 22.0 (increase of 10.0%) |

On the basis of the conducted researches of the diesel engine dependences of influence of its modes of operation on NG on indicators of process of combustion are established. Optimum values of indicators of combustion process at work of the diesel engine on NG at $\Theta_{\text{inj}}=23^\circ$ and $\Theta_{\text{inj}}=26^\circ$ are defined.

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