The ability of natural gas to reduce soot content in diesel exhaust gases

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Abstract. In accordance with the priority directions of development of the motor transport complex of the RF, the use of NGV fuel in transport should expand and by 2035 reach 50% of the total number of trucks and buses in large cities. This is due to a number of factors. The paper presents the results of studies confirming the effectiveness of using natural gas to reduce soot emissions with exhaust gases. In particular, the dynamics of the formation and burnout of soot particles by the angle of rotation of the crankshaft at the working operating mode is considered.

1. Introduction

The expansion of the use of NGV fuel is due to a number of positive qualities of natural gas as a fuel for internal combustion engines. First of all, it is widespread in nature and relatively easy accessibility for extraction and ease of processing. Secondly, the relatively low cost of natural gas fuels compared to petroleum fuels. For oil fields in Russia, this price difference is 2-2.5 times, which naturally makes NGV fuel very competitive in comparison with traditional gasoline and diesel fuel.

But the most important factor, in our opinion, why it is necessary to expand the use of natural gas in transport is its environmental friendliness in comparison with diesel fuel. Reducing exhaust pollutant emissions is a top priority for engine builders around the world. The level of emissions of harmful substances into the atmosphere today is so great that the issue has become global for the entire world community. And the resolution of this issue can no longer be postponed [1-5].

Moreover, we can safely say that gas-powered vehicles are even more environmentally friendly than electric vehicles, no matter how paradoxical it may sound. Although an electric vehicle does not emit harmful compounds into the atmosphere during operation, a very large amount of them is emitted during its production, or rather the production of storage batteries. Recycling and disposal of used batteries is equally harmful to the environment. And this is not counting the increase in the load on the electrical
networks when charging electric vehicles, which means more fuel combustion on thermal fuel and energy plants [6-9].

Based on the foregoing, it can be argued with a high degree of confidence that in the near future the use of NGV fuel will only expand and become a real alternative to traditional diesel fuel.

2. Materials and Methods

To accomplish this task, using computer modeling, we calculated the content of solid carbon particles in the ICE cylinder using methane as a fuel and in comparison with the basic diesel modification.

Our calculations showed that active combustion of fuel begins immediately after the piston passes VMT. This leads to a rapid increase in the temperature of the working mixture, which strives to reach its maximum values. Knowing the heating capacity of the fuel, we obtained the values of 2120 K for the basic modification and 2480 K for the methane one. As for the formation of carbon particles, there is the influence of two oppositely directed processes: creation and oxidation. The final amount of particles in the exhaust gas will also depend on which of these processes will make the greatest contribution [10-16].

3. Results and Discussion

Immediately after VMT, the amount of solid carbon in the cylinder rapidly increases due to the large amount of fuel, its uneven distribution over the volume, and the fuel flares become centers of the formation of soot particles in conditions of a lack of oxygen. An increasing volume of the cylinder is involved in the combustion process and the creation of soot particles is accelerated. Since the temperature in the fuel jet is relatively low, the rate of combustion of particles is low and more of them are formed than are burned out. In this case, the so-called NTF mechanism works. At this stage, there are many zones re-enriched in fuel in the cylinder, which means that conditions will be created for the formation of carbon particles [17-24].

At temperatures below 1500K, soot particles are formed faster than oxidized, which means that the total number of particles grows.

As the combustion process develops and the average temperature in the cylinder rises, as well as the presence of free oxygen, carbon oxidation reactions intensify and this process begins to dominate in the expanding volume of the cylinder. At the same time, the rate of particle formation also increases, since the mechanism of soot formation through acetylene begins to work. Different processes dominate in different volumes of the cylinder, but if you look at the integral indicator, then the number of particles per unit volume is still increasing [25-33].

At the final stage of the expansion process under conditions of high turbulence of the charge, high temperature of gases and the presence of a sufficient number of oxygen molecules, the processes of oxidation of carbon particles become predominant. The presence of turbocharging also plays a significant role in this process. The increased density of the air charge together with the increased temperature favors the intensification of diffusion processes, molecular interactions become more active and this contributes to the fact that oxidative processes occur on the surface of these particles and the total amount of carbon particles decreases [34-39].

Investigating the properties of soot particles formed during fuel combustion, we carried out a thorough analysis of them, including microphotography of soot particles using electron microscopy, for a comprehensive study of their structure and properties. The results of these studies are shown in figure 1.

From the point of view of the kinetics of the formation and oxidation of particles, the particle size distribution, the determination of the characteristic particle size, by which one can judge the reactivity of the particles, is of great importance. Similar studies have also been carried out. Some of the results are shown in figure 2.

The figure shows that most of the particles have a typical size of the order of 20-40 nm. Larger particles are the result of the conglomeration of small single particles [40-44].
Figure 1. Micrographs of the shape and particle size of diesel soot particles (sample 1) obtained with different magnifications of the JEOL JSM-6510 microscope: a. ×50; b. ×100; c. ×1,000; d. ×5,000; e. ×10,000; f. ×20,000.
Figure 2. A series of experimental data on the particle size of soot (sample 1).

Figure 3. The distribution of soot particles by size (sample 2).

Figure 4. The distribution of soot particles by size (sample 3).

Figure 5. The distribution of soot particles by size (sample 4).
4. Conclusions
As a result of the studies, the sizes and functions of the particle size distribution for various soot samples were established. The dispersion of soot particles is determined by the sampling location and the type of fuel used. The formation of soot is a volumetric process of thermal decomposition (pyrolysis) of hydrocarbons in the gas phase under conditions of a severe lack of oxidizing agent (oxygen). The initial soot particles formed in the cylinder have sizes up to several tens of nanometers. From such particles aggregates are formed, having sizes up to several micrometers [45-48]. The study of the particle sizes of soot and the mechanisms of their formation is necessary when considering the processes occurring in the internal combustion engine and determining the heat stress, efficiency and wear resistance of the engine structural elements.

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