The effect of the use of natural gas on the emissivity of a flame in a cylinder of an automobile diesel engine

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Abstract. The issues and features of heat transfer in the cylinder of a high-speed diesel engine of 4CHN 11,0/12,5 dimension when working on diesel and gas engine fuel (gas-diesel process) are considered. The spectral and integrated radiation characteristics of soot particles in the cylinder of the 4CHN 11,0/12,5 gas diesel engine were calculated depending on the angle of rotation of the crankshaft.

1. Introduction
Diesels are non-alternative power plants in automotive, tractor and agricultural engineering, and their characteristics, ultimately, determine the operational, energy, economic, environmental and overall dimensions of the equipment used.

In modern piston diesels, the workflow is characterized by the intense occurrence of thermal and gas-dynamic processes. It is necessary to strive to ensure that these processes provide an improvement in the effective performance of diesel engines. An accurate analytical description of the set of physicochemical processes associated with heat transfer and occurring in diesel engines has not been created due to the complexity of these phenomena and the multiplicity of factors affecting them. Moreover, the recent increase in the number of developments on the use of alternative fuels in diesel engines (compressed natural gas, alcohol fuels, fuels based on vegetable oils, etc.) does not seriously consider heat transfer processes at all. Therefore, work aimed at studying and improving work processes in diesel engines, including when working on alternative fuels, are in demand and far from being studied [1-9].

The issues of heat transfer, which in relation to piston internal combustion engines is of a pronounced local character, are of major applied value.

The heat exchange process in the combustion chambers (CC) of diesel engines is radiation-convective or complex. Therefore, when studying such heat transfer, it is necessary to solve the radiative energy transfer equations in conjunction with the equations describing the gas dynamics and hydrodynamics of the processes and convective heat transfer [10-15].

When considering radiative heat transfer in a diesel cylinder, it is assumed that the working fluid in the cylinder is a medium that emits, absorbs and dissipates thermal energy. Moreover, the working fluid is a dispersed medium, since it contains soot particles in its volume, which are the main generators of thermal radiation. Like temperature, the local concentration of soot particles in the cylinder volume is heterogeneous. It depends on the mode of operation, the angle of rotation of the crankshaft and mass transfer, i.e. directions and intensities of convective flows in the cylinder.
Accordingly, the attenuation coefficient of the beam, which is one of the most important optical parameters of the medium, will change, since its value depends on the concentration of suspended particles.

In addition, during the working cycle in the cylinder there is a multicomponent medium consisting of gases (air and gaseous products of combustion), fuel vapors, droplets of liquid fuel and solid soot particles. All this must be taken into account when determining the total heat fluxes perceived by the walls of the combustion chambers [16-21].

2. Experimental part
The radiation from the medium inside the diesel cylinder is continuous and similar to gray body radiation, but uneven. And the presence in the volume of soot particles greatly increases the intensity of thermal radiation

As has already been noted, many factors affect the thermal radiation in a diesel cylinder. In [4], they are divided into four main groups. With regard to diesels, they have their own characteristics.

Firstly, these are the geometric parameters of the emitting volume. Since the shape and dimensions of the combustion chamber are different for different types of diesel engines, the number of spray holes for nozzle, the shape and direction of air flows in the compressor station, the type of mixture formation are different, and the heat flow will be different.

Secondly, the radiation characteristics of the condensed phase. These include optical constants (refractive indices and absorption), sizes and size distribution of particles (primarily carbon black), the chemical composition of the condensed phase, etc.

Thirdly, the radiation characteristics of the gas phase. These include chemical and thermal nonequilibrium in the CC, the wavelength and spectral range of radiation of the main components of the phase, temperature and its distribution in the CC, gas pressure, chemical composition of the medium, optical properties of the gas phase, and a number of other parameters.

Fourth, the physical characteristics of surfaces that limit the emitting volume. This is the temperature of the bounding surfaces, and the reflective and radiating abilities of the surfaces, and the boundary conditions. In relation to piston internal combustion engines, in the first place, the piston and cylinder head are considered. To a lesser extent - cylinder walls.

To calculate the radiation heat flux in a diesel engine, it is necessary to know the temperature of the emitter, the degree of blackness of the emitting and absorbing medium, and the degree of blackness of the surfaces of the diesel engine [22-28].

As for the temperature of soot particles, most researchers agree that the temperature of the particles and the temperature of the gas surrounding them can be assumed the same. Although there is a different opinion. So, in some works it was shown that the temperature difference between soot particles and gas does not exceed 1 K for particle sizes up to 0.3•10^{-6} m. In another work, the same temperature of soot particles was experimentally shown for particles about 8•10^{-8} m in size and gas with an error of ± 60 K [1].

Blackness ε refers to the most important radiation characteristics. It depends on the nature of the body, temperature and surface roughness. The degree of blackness of the working fluid in the diesel cylinder during the cycle depends on the load. In previously published works on this subject, diesel flame is considered as a gray body, i.e. radiating in all wavelength range λ. In this case, the bulk of the radiated thermal energy falls on a certain range. In different sources this range is different, but on average it is [0.5, 10] microns.

In [1], an empirical formula is given for determining the degree of blackness of the working fluid depending on the angle of rotation φ of the crankshaft and the average effective pressure of the re-gases in the cylinder:

\[ \varepsilon = 2^{0.21 p_e} (0.6866 - 0.3274 p_e) \phi^{0.1537+0.265 p_e} \exp\left(-0.014388 + 0.006162 p_e\right) \phi, \]

where \( \phi \) is the angle of rotation of the crankshaft, ° p.k.v.
\( p_e \) - average effective gas pressure in the cylinder, MPa.
However, this expression is applicable only to diesel engines running on traditional diesel fuel. How applicable it is to fuels with a different chemical structure needs to be checked additionally. Interesting results of the experimental determination of the local temperatures of the working fluid in the ICHN 18/20 diesel cylinder by the color temperature method are given in [2]. The study was carried out at values of $p_e = 0.5...0.6$ MPa and $n = 1500$ min$^{-1}$, photo and filming was carried out with a frequency of 4000...5000 frames per second. It was experimentally established that the working fluid in the cylinder has a very inhomogeneous temperature field with a wide range of temperature gradients (from 30...70 K/mm inside one zone to 300...500 K/mm at the borders of burned and unburned zones). In addition, it turned out that when operating on diesel fuel, a temperature above 1700 K has approximately 28% of the working fluid mass in the cylinder, more than 2000 K - 27%, more than 2200 K - 22%, more than 2400 K - only about 2% and more than 2600 K - about 0.2%. The rest of the working fluid (about 20%) has a temperature of less than 1700 K.

All the more interesting are the issues related to the study of local and boundary zones and the processes occurring in them when the diesel engine is operated using fuels of a different chemical composition and, more importantly, a different chemical structure. Compressed natural gas has a number of differences in its motor properties from petroleum diesel fuel, and the use of the gas-diesel process leads to the formation of local zones that directly affect the processes of soot formation and oxidation of soot particles. This, in turn, affects the intensity of radiant heat transfer.

The supply of a pilot portion of diesel fuel leads to the formation of zones with a lack of oxidizing agent in the core of the flares and, accordingly, soot formation processes in these zones will be predominant. At the same time, with the further development of flares, new portions of the methane-air mixture will be involved in the combustion processes, in which the soot particles will be oxidized. And, as you know, the combustion of soot particles is accompanied by the release of a large amount of radiant energy.

We studied the operation of a diesel engine using compressed natural gas supplied to diesel cylinders along with an air charge ignited by a pilot portion of diesel fuel supplied through a standard power system (the so-called gas-diesel process) and examined the optical properties and radiation characteristics of a flame in a diesel cylinder.

A feature of such studies is the presence of a large number of components in the combustion products of another carbon-hydrogen ratio in the fuel molecule, their heterogeneity, that is, the presence of a gas and solid phase, which, of course, affects the emissivity and absorption of the medium, the degree of blackness flame and other radiation characteristics.

In our calculations, we used complex programs for modeling the optical properties, radiation characteristics, and thermal radiation of the «SPEKTR» and «CARBON».

The comprehensive program «SPEKTR», developed in the FORTRAN language, is designed to calculate the radiation characteristics (RC) of heterogeneous combustion products (HCP) of internal combustion engines. It allows one to carry out calculations for the real components of the gas and condensed phase of the gas-pressure station with any distribution of condensate particles in a wide range of thermo- and gas-dynamic parameters. The «CARBON» program calculates the RC of ICE combustion products.

The initial data for the calculations are: dimensions and geometry of the emitting volume, radiation characteristics of surfaces, gas and particle temperatures, pressure, mass fraction of condensate, molar mass, particle density, particle size distribution function, optical properties, concentration of the main components of the gas phase. The calculation results are the RC of individual particles and unit volume, the coefficients of the expansion of the indicatrix in a series by Legendre polynomials, spectral and integral flux densities, spectral and integral degrees of blackness.
According to the same work, the temperature in the core of the torch is 900...1000 K, while the gas temperature in the volume of the compressor is from 1200 to 1800 K, depending on the angle of rotation of the crankshaft [24, 28, 30].

3. Conclusion
For the CC of diesel engines, when calculating the radiant heat transfer, it is necessary to take into account a number of specific features related to both the non-stationary nature of the process and the geometry of the CC and torch in it. Depending on the degree of turbulence of the air flow in the chamber and the shape of the fuel jet, a soot particle concentration field is formed. The presence of a finite duration of fuel injection, the polydisperse composition of the fuel droplets in the flare, the uncertainty of the coordinates of the self-ignition centers, the turbulence of the intracylinder volume as a result of the movement of the piston and the combustion process, its constantly changing volume, the constantly changing concentration of soot particles and their dispersion composition practically exclude the possibility of directly calculating instantaneous local concentrations and dispersion composition of soot particles, which is necessary for calculating radiant heat sharing [22, 24].

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