Reduction of soot carbon in the exhaust gases of a tractor gas-diesel engine

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Abstract. The rate of oxidation of carbon (including its dispersed forms) has a value much higher than the rate of gasification. Therefore, in the initial part of the flame, when oxygen is still contained in the gas phase, the oxidation of soot will be the process on which the change in the size and concentration of dispersed carbon particles mainly depends. The intensity of oxidation and gasification of dispersed carbon in the flame largely depends on the development of the mixing process, determined by the aerodynamics of the fuel and air jets. The paper presents an analysis of the influence of mixing processes on the oxidation and gasification of dispersed carbon in a natural gas flame in the study of homogeneous flames and mixing of turbulent jets. The results of industrial studies of the mixing of fuel and air in a diffusion torch are taken into account. The results allow us to evaluate the influence of various aerodynamic factors on the processes occurring in the glowing flame of natural gas in the combustion chamber of gas diesel.

1. Introduction

Methane is the basis of natural gas, so the laws of the methane pyrolysis process are crucial for the decomposition of natural gas.

As is known, the process of decomposition of methane into elements is described by the following total reaction equation [1-3]:

\[ CH_4 \rightarrow 2H_2+\text{C}. \]

Thermodynamically, this reaction is well studied and well covered in the literature [4-7]. A number of papers are devoted to the calculation of equilibrium under different conditions and at different temperatures [8-12]. Common to these works is that calculations based on the use of the equilibrium constant confirm the practical disappearance of methane at temperatures exceeding 800°C, and also show the impossibility of the existence of intermediate decomposition products.

Both are refuted by numerous experimental works discussed below. The results obtained in these studies allow us to conclude that equation (1) can be considered only as the total equation of the methane
decomposition reaction. Without exception, all the work carried out in this direction indicates the complex nature of the methane decomposition reaction, which proceeds through intermediate stages.

2. Methods and Materials
One of the first works that allowed us to draw interesting conclusions was the work of Fischer, who showed in the temperature range of 900-1150°C that a significant amount of liquid aromatic hydrocarbons – benzene, toluene, xylene-is formed during the decomposition of methane. The gas phase contained acetylene, ethylene, ethane and others. The maximum yield of liquid hydrocarbons in Fischer’s experiments reached a very significant value – 12.9% (of the mass of methane taken). Fischer found that for the formation of higher hydrocarbons during the pyrolysis of methane, the time of the process is as important as the temperature [13-15]. He showed that the intermediate products during the decomposition of methane are formed by polymerization of free radicals CH₃, CH₂, CH.

Important results from a practical point of view were obtained in the works of Peters and Mayer. For a wide range of temperatures and time, they obtained a dependence that establishes a relationship between the temperature of the decomposition reaction and its duration. From these data, it follows that in a certain temperature-time interval, along with carbon, intermediate products of methane decomposition are obtained. Thus, in a certain temperature-time region, along with carbon, benzene is formed as an intermediate product. During the preliminary reformation, the methane decomposition reaction proceeds through intermediate products of the aromatic series, which are formed by polymerization of free radicals CH₃, CH₂, CH. Thus, it can be considered an undoubted fact that the process of methane decomposition occurs through the formation of intermediate aromatic and polycyclic compounds that undergo dehydrogenation and compaction of molecules [16-19].

![Figure 1. Change in the indicators of soot content in the cylinder of a turbocharged diesel engine: —— diesel fuel; —— natural gas.](image-url)

Both from the point of view of setting up the experiment and from a practical point of view, questions about catalytic phenomena during methane pyrolysis, as well as about the influence of diluent gases on the process, are important. At present, it can be considered an established fact that quartz and phosphorus do not have a practically catalyzing effect on the decomposition of methane. Carbon, especially graphite, has a very significant catalytic effect on the decomposition of methane. This fact is of great practical importance. With regard to the thermal pyrolysis of methane, it can be considered established that the development of the process is determined by kinetic laws, and the decomposition of methane passes through the formation of intermediate aromatic and polycyclic compounds. The catalytic effect of the carbon surface on the process of methane decomposition leads to the formation of dispersed carbon, which can also have a catalytic effect on this process.
3. Results and Discussion

Thus, the decomposition of methane, apparently, is also inherent in autocatalysis, more precisely, microheterogenic autocatalysis. Thus, from the kinetic point of view, the process of deep decomposition of methane seems to be a process of enormous complexity. An exact kinetic description of this process is not yet possible, since the catalytic and adsorption properties of the carbon black surface and dispersed carbon are poorly studied. At the same time, to solve numerous practical problems, an appropriate kinetic equation is necessary, which allows us to obtain a solution at least in an approximate global form. Under such conditions, the only possible, apparently, is the application of the kinetic provisions to this process with the determination of the effective reaction rate constant and the apparent activation energy.

Along with thermal pyrolysis, a process that takes place without an oxidizer, in some cases, methane decomposition occurs in the presence of an oxidizer, most often air oxygen, when natural gas is reformed during its partial oxidation. Natural gas is reformed to release a dispersed phase during methane pyrolysis, which significantly increases the emissivity of the flame. Thus, the dispersed phase suspended in the gas phase is the product for which the decomposition of methane is carried out as the main component of natural gas. However, it is extremely difficult to control the process of methane decomposition in the dispersed phase. Therefore, it is controlled by the residual methane or, in other words, by the degree of decomposition of methane [20-23].

![Figure 2. Probability density distribution of $N(x)$ soot particle sizes in a turbocharged gas diesel cylinder.](image)

The temperature at which methane pyrolysis takes place is determined by a number of thermal engineering factors. The main one in the thermal pyrolysis of methane at its constant consumption is the intensity of the system supply with heat, which finds its concrete expression in the temperature that is maintained on the walls of the combustion chamber where decomposition occurs. During oxidative pyrolysis, the value of the excess air coefficient has a great influence on the process temperature. A certain temperature, determined by the above-mentioned factors, is reached during thermal pyrolysis during gas heating. In oxidative pyrolysis, the temperature of the beginning of decomposition is reached very quickly, since part of the gas is oxidized. When studying the kinetic dependences of the methane pyrolysis process, all the constants of the process rates can be attributed only to the average temperature, since it is almost impossible to accurately determine local temperatures.

The radiation properties of the flame depend on the size and unit concentration of soot particles suspended in the gas phase. Therefore, the question of how the dispersed phase occurs during methane pyrolysis is important and interesting. It should also be borne in mind that the entire gas cannot
simultaneously reach a certain temperature and its individual micro-volumes can be heated in different ways. Therefore, carbon black is also present in the decomposition products along with intermediate products. Figures 1 and 2 show the concentration and probability density distribution of $N(x)$ soot particle sizes in a turbocharged gas diesel cylinder.

4. Conclusion
Thus, there is every reason to believe that the formation of carbon in the cylinder of a gas-diesel is due to the formation of very large and possibly unstable molecules that have arisen as a result of the polymerization of radicals and are capable of further graphitization.

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