TO THE THEORY OF IGNITION AND DETONATION OF COAL PARTICLE GAS MIXTURES

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The urgency of the problem of coal gas mixture ignition and detonation is caused by this medium wide use as fuel mixture in power facilities and by the problems of the combustion and fire safety in coal-mining and power industries.

There are a numerous papers devoted to the theoretical study of this problem. The critical ignition/extinction conditions of Semenov's thermal explosion theory were used widely in the studies performed in the frame of the point-wise approximation models of ignition of coal samples and aerosuspensions. The simplified kinetic description accepted in most papers promotes this framework. The attempts were done also to attract the theory of thermal-chain explosion technics for theoretical analysis of the processes. The description of thermal and mass transfer processes either in gaseous media surrounding a single reacting particles, or in two-phase mixture flows is typifying for the papers performed on the basis of the distributed approach. In both cases ignition and burning were usually considered as unified reaction process. The equations of mechanics of heterogeneous media in one or another approach were attracted for modeling of coal aerosuspension flows too.

In this paper a mathematical model of ignition of a multicomponent coal aerosuspension is presented within a point-wise approach of mechanics of heterogeneous media. The problem of coal gas mixture ignition behind a reflection shock wave is solved as an application. The second part of the paper is devoted to the problem of mathematical modelling of detonation processes in coal particle gas mixtures.

The mathematical model of ignition takes into account basic influential physical and chemical processes. These are pyrolysis of fuel particles, oxidation of volatile matters and coke, convective and radiation heat interphase transfer. The two-phase medium is considered to be a multicomponent mixture. The gas phase consists in oxygen, combustible volatile matter, gaseous product of volatile matter combustion and carbon oxidation reaction, inert components of initial gas mixture and volatiles. The dispersed phase consists in condensed volatile matter component, carbon and inert component of fuel (ash). Formal kinetics of pyrolysis and oxidation reaction has a global character.

The initial problem for a stiff system of nonlinear ordinary differential equations is solved. This mathematical model involves phase and component mass conservation laws and heat exchange laws. A number of difficulties of qualitative and quantitative investigation of model centre around an appearance of critical phenomena for exothermal reactions and possible «damping» influence of a devolatilization process.

The distinctive variants of the mixture thermal history realized under various proportions between relaxation times of nonequilibrium processes are shown:

- heterogeneous ignition due to coke oxidation reaction
- homogeneous ignition by means of gas phase volatiles matters reaction
- hybrid ignition due to coke and volatile matter oxidation processes simultaneously.

The model verification is realized using the experimental data of [1] relating to the ignition delay times of the mixture of the coal particles with air and oxygen under conditions behind reflecting shock wave. The calculated dependence of the ignition delay time of the coal particle aerosuspension on the gas temperature behind shock wave is shown in Fig. 1 for the values of volatiles initial mass fraction 26% (curve 1), 17% (2) and 9% (3). The satisfactory coincidence of theoretical data and experimental data (denoted by symbols) demonstrates the model efficiency in a rather wide range of parameters.

The problem of the coal aerosuspension detonation has already been under discussion in literature. Nevertheless, it seems available to us to revise it on the basis of some simplified assumptions concerning the kinetic process of combustible mixture component oxidation. And the purpose is fast estimation of an opportunity of detonation regime of combustion initiation.

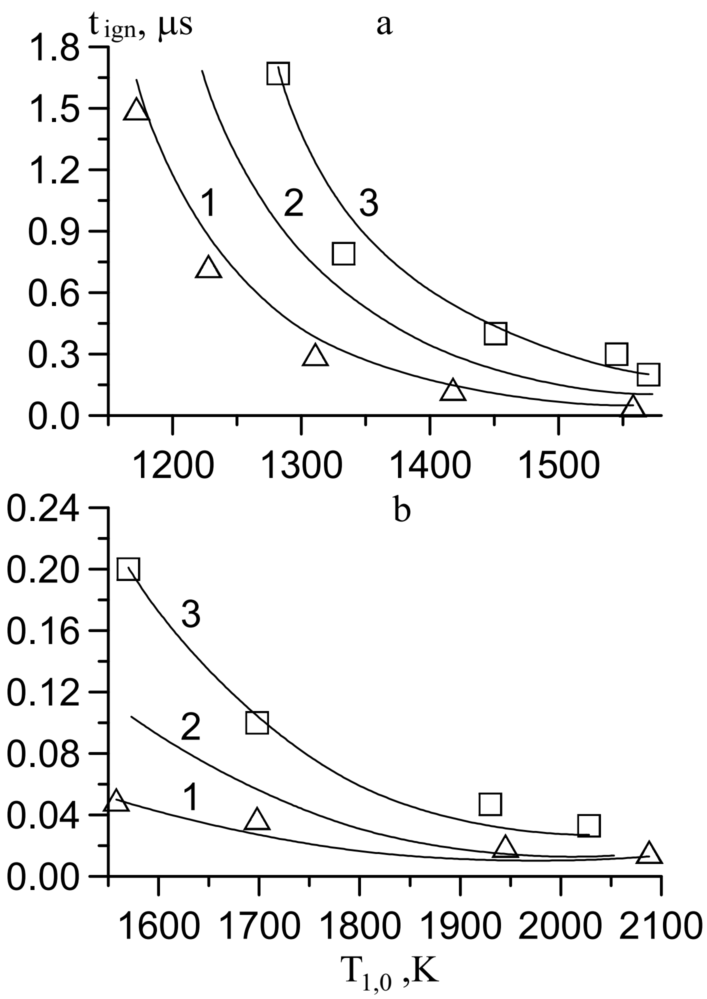

Figure 1

A mathematical model of detonation of coal dust in air and oxygen was developed for the purpose mentioned. The model is based on the conceptions of mechanics of heterogeneous media in one-velocity two-temperature approach including global chemical kinetic equations for pyrolysis, coal-volatile matter combustion, and coke combustion processes. The values of the generalized constants characterizing chemical reaction heat release just as the values of the characteristic times of the combustion and pyrolysis processes are determined partly from the literature sourses. Also the correspondence of calculated results and known experimental data [2] on the dependence of detonation velocity on initial coal particle concentration in the mixture is taken into account.

The stationary regimes of heterogeneous detonation of coal aerosuspension are investigated by means of analysis of the ordinary differential equations system describing nonequilibrium flow of the mixture behind the stationary detonation wave. Comparison of the estimated values of characteristic times of velocity relaxation process, pyrolysis, coal-volatile matter combustion, and coke combustion processes appears the following.

The carbon combustion takes place mainly when the other processes (heat relaxation, coal-volatile matter combustion) are over, that is practically in equilibrium medium. Therefore total heat release is always monotonic and weak detonation regime (the solution with an internal sonic point) is not realized at particle concentration values less then stoichiometric point. The only possible normal stationary regime can be Chapman-Jouguet detonation wave. For large-size particle fractions and at significant concentration excess over the stoichiometric value this condition is violated because gas and particle heat exchange goes on after the combustion process finishing. Then the total heat release becomes non-monotonic and internal singular point of saddle type arises in the solution. This point is sonic point with respect to frozen sound velocity. In this case weak stationary detonation regime can be obtained.

The flow structure behind the detonation wave front in coal mixture at initial parameter values and conditions corresponding to experimental data [2] is analysed on the basis of numerical investigation. The calculations were carried out for two particle fractions (the size of particle is 50 μm and 25 μm) and two concentration values: close to stoichiometric composition (36% of the mixture mass value) and poor (15% of the mixture mass value). It is obtained that for coal qualities with poor volatile matter content (16% for particle size of 25 μm) the procees of volatile matter combustion exceeds the heat relaxation process, and concequently the ignition delay time. Therefore the assumption about instantaneous character of volatile matter combustion accepted in several books (for example, [3]) is not allowed be justified. Although the volatile matter combustion energy release in this case is sufficiently less then the energy release at coke burning and is comparable with the energy expending for the particle heating to the equilibrium temperature behind the frozen shock wave. For coal fractions with large volatile matter content (50 μm, volatile matter concentration 32%) the processes of pyrolysis and volatile matter combustion are still more delayed because the state behind the frozen shock wave in the mixture is characterized lower gas pressure and temperature values. The propagation velocity in accordance to [2] decreases from 1.5 km/s for 25 μm to 1.28 km/s for 50 μm. A characteristic feature of the coal aerosuspension detonation regimes is that the sufficient particle density rising behind the detonation wave (ρ - cloud) is not observed. For low-velocity detonation regimes the equlibrium temperature behind the detonation wave front does not exceed the ignition limit, therefore the ignition delay here is entirely determined by the processes of pyrolisys and volatile matter combustion.

The analysis of velocity relaxation zones and comparison of the characteristic times of velocity relaxation and combustion processes in the mixture allows to make the conclusion that practically all investigations of detonation processes in coal aerosuspensions can be made in the frame of one-velocity approach.

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