CONTROL OF IGNITION AND DETONATION PROCESSES IN REACTIVE GAS MIXTURES BY ADDITIONS OF INERT COMPONENTS

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Abstract: The paper presents a large-scale theoretical and numerical study of ignition and detonation processes in gas mixtures with dispersed components (porous filters, clouds of inert and reactive particles, and liquid droplets) in order to control explosive processes and prevent and supress detonation. The influence of inert and reacting particle parameters on the ignition processes of reacting gas mixtures is determined. Limiting particle concentrations for preventing ignition are obtained. The opposite effect of iron and coal particles on ignition processes has been established. A classification of detonation regimes of interaction of detonation waves with inert components has been carried out. Concentration and geometric limits of detonation have been found. Universal criteria for detonation failure have been obtained, linearly linking the diameter and volume concentration of inert components. The invariance of concentration limits upon transition from microsized to nanosized inert components has been established. Optimal configurations of inert components leading to complete suppression of cellular detonation have been determined. It has been established that systems of two filters located near the channel walls are optimal for detonation suppression.

Keywords: numerical modeling; cellular detonation wave; inert components; detonation attenuation; detonation suppression

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Figure Captions

Figure 1 Dependences of the maximum ignition temperature of hydrogen/silane/air mixtures on the volume concentration and diameter of SiO_2 particles: *1* — $2H_2 + \text{air}$; *2* — $1.6H_2 + 0.1SiH_4 + \text{air}$; *3* — $1.2H_2 + 0.2SiH_4 + \text{air}$; *4* — $0.8H_2 + 0.3SiH_4 + \text{air}$; *5* — $0.4H_2 + 0.4SiH_4 + \text{air}$; *6* — $0.5SiH_4 + \text{sir}$; black filled signs — $d = 100$ nm; grey filled signs — 1 μm; and empty signs — $d = 10$ μm

Figure 2 Dependences of the ignition delay time of the methane – air – reacting particles mixture on the initial temperature of the mixture: signs — experiments [25] and lines — calculations (*1* — $CH_4 + \text{air}$; *2* — $CH_4 + \text{air} + Fe$, reduced kinetics; and *3* — $CH_4 + \text{air} + Fe$, point model)

Figure 3 Dependences of the ignition delay time of the stoichiometric methane–air mixture on the temperature and concentration of coal particles: *1* — $CH_4 + \text{air}$, $t_{\text{ign}}(CH_4)$; *2–4* — $CH_4 + \text{air} + C$, $d = 26$ мкм (*2* — $m_2 = 2{,}5 \cdot 10^{-4}$, $t_{\text{ign}}(CH_4)$; and *3* and *4* — $m_2 = 5 \cdot 10^{-4}$: *3* — $t_{\text{ign}}(CH_4)$; and *4* — $t_{\text{ign}}(C)$)

Figure 4 Dependences of the ignition delay time of coal microparticles in a coal–air mixture (*a*) and of coal and methane microparticles in a methane–coal–air mixture (*b*) on temperature: filled signs — experiments [41]; empty signs — calculations; *1* — $t_{\text{ign}}(C)$; and *2* — $t_{\text{ign}}(CH_4)$

Figure 5 Distributions of normalized velocities of the shock wave (black curves) and combustion front (grey curves) in the channel: signs — experiments (*1* — [8]; *2* — [6]; *3* — in the gap; and *4* — in the filter)

Figure 6 Dependences of the normalized critical length of the filter on the volume concentration of filter particles: *1* — $d = 50$ μm; *2* — 100; and *3* — $d = 200$ μm

Figure 7 Critical volume concentration of particles as functions of particle diameter, detonation concentration limits: signs — calculations; curves — approximations; *1* — $0{,}5SiH_4 + \text{air}$; *2* — $0.4SiH_4 + 0.4H_2 + \text{air}$; *3* — $0.3SiH_4 + 0.8H_2 + \text{air}$; *4* — $0.2SiH_4 + 1.2H_2 + \text{air}$; *5* — $0.1SiH_4 + 1.6H_2 + \text{air}$; and *6* — $2H_2 + \text{air}$

Figure 8 Normalized detonation velocity in a hydrogen–air mixture as a function of the volume concentration of inert particles. Comparison of one-dimensional (empty signs) and two-dimensional (filled signs) calculations (crossed out signs — detonation failure): *1* — $d = 100$ μm; *2* — 10 μm; *3* — 1 μm; and *4* — $d = 100$ nm

Figure 9 Triple point trajectories ($m_2 = 5 \cdot 10^{-5}$): (*a*) $d = 100$ nm; and (*b*) $d = 1$ μm. Propagation of attenuated detonation wave

Figure 10 Triple point trajectories: $d = 100$ μm and $m_2 = 10^{-4}$. Propagation of attenuated detonation wave

Figure 11 Critical volume concentration of particles as a function of particle diameter. Comparison of one-dimensional and two-dimensional calculations: *1* — planar detonation wave; *2* — cellular detonation wave; *3* — calculation [44]; *4* — calculations [45]; and *5* — experiment [46]

Figure 12 Normalized detonation velocity in a hydrogen–air mixture as a function of volume concentration. Comparison of detonation suppression efficiency by particle clouds (empty signs) and droplet curtains (filled signs) (clossed out signs — detonation failure): *1* — $d = 50$ μm; *2* — 100; and *3* — $d = 200$ μm

Figure 13 Critical lengths of droplet curtain (*1*, BR = 1), particle cloud (*2*, BR = 1), and filter (*3* — BR = 1; and *4* — BR = 0,16) as functions of diameter

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