SHOCK AND DETONATION WAVE PROPAGATION ALONG REACTIVE PARTICLE CLOUD IN CHANNEL

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Shock and detonation wave propagation in a channel partly filled with a cloud of solid reactive particle aerosuspension is investigated. The half-infinite rectangular shaped cloud is situated longitudinally the plane of symmetry. A plane shock wave propagating along the channel is considered as an initiation factor.

The problem in studied on the basis of numerical modelling of two-dimensional two-phase reactive media flow. The governing equations follow from the conservation laws for mass, momentum, and energy of each phase in two-velocity two-temperature approach of mechanics of heterogeneous media. The dependence of drag coefficient on relative Mach number of supersonic gas flow past the particle and the correlation between Nusselt and Reynolds numbers in heat exchange are taken into account in phase interaction processes. The system is enclosed by the equations of state and by equation of global chemical reaction of particle combustion. The finite-difference scheme of TVD-type for gas and the Mac-Cormack scheme for particle phase are applied for numerical simulation.

The calculations are carried out for mixture of small (from 1 to 5 μm) aluminum particles and oxygen in ratio of prectoichiometric composition. The channel width H is 20 cm, the cloud width h varies from 4 cm to 18 cm. The incident shock wave amplitude determined by the Mach number with respect to initial state of the gas varies from 3 to 5. The channel walls are assumed to be smooth and non-heat-conducting.

The model used has been adapted to the experimental data of Strauus on the dependence of normal detonation wave velocity on the initial particle concentration in the mixture. The analysis of stationary detonation flows of aluminum aerosuspension in the frame of the model used has been worked out in [1]. Problems of the shock-wave initiation of detonation in one-dimensional approach were discussed in [2]. The scenarios of detonation developing depending on the incident shock wave strength were studied and the criteria of detonation initiation for monodisperse mixtures of various particle diameters were obtained. Some two-dimensional effects at the shock wave interaction with the particle cloud of finite width were considered also in [2], but stationary detonation structures in the aerosuspension of 50 μm particles were not obtained.

The present calculations of the flow of small (1-5μm) solid particle aerosuspension in the cloud of finite width under the shock wave action appeared the following. The interaction of the plane shock wave with the cloud leads to the front refraction on the cloud lateral boundary and the refracted front is reflected from the plane of symmetry. The shock wave propagation along the cloud turns out to have a steady-state character. The reflection of the plane of symmetry can be either regular or with the Mach stem appearing. Figure 1 shows pressure shadow reliefs in the channel of 10 cm width past 0.25 ms after the shock wave entering into the cloud with aluminum particle diameter of 1 μm depending on the cloud width. The refracted shock (black line) propagates from left to right and the position of the cloud left boundary is about 0.35 cm. One can see that regular character of reflection at 8 cm is replaces by Mach type of reflection at 12 cm. Thus, which type of the reflection takes place depends on the relative cloud width *h/H*.

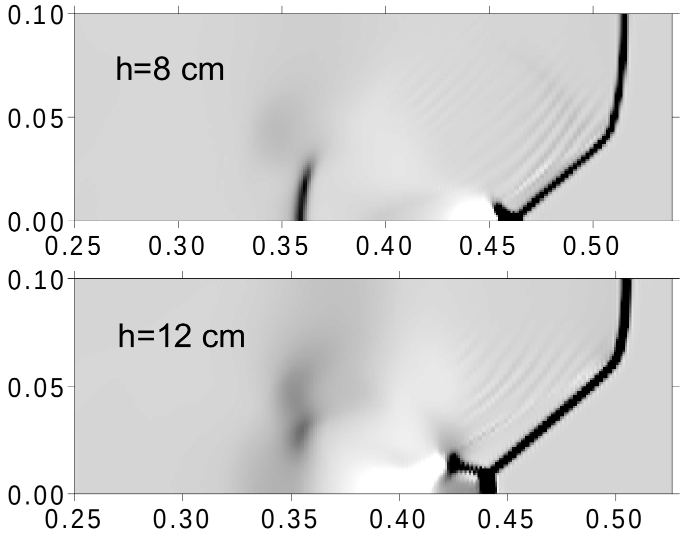

Figure 1. Pressure shadow relief at 0.25 mc, M_0=3, *d*=1 μm.

A third type of the reflection is realised in the aerosuspensions with particle diameter of 5 μm. In this case the relaxation zone width in the mixture is comparable with the transverse cloud size. Then the Mach stem becomes thicker and the reflected shock wave adjoining to the Mach stem is situated inside the relaxation zone behind the incident shock wave and also is smeared (Figure 2).

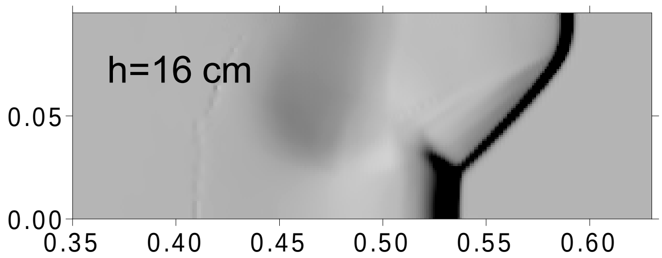

Figure 2. Pressure shadow relief at 0.3 mc, M_0=3, *d*=5 μm.

The sharp turn of the contact surface take place at the shock wave refraction on the boundary separated the mixture from the pure gas. At that the particle cloud is compressed in transversal direction. The region of the flow turning has triangular shape and is bounded by the leading shock wave front, contact surface, and the reflected shock wave front. The region appears as dark grey triangular zone denoted by *A* in longitudial gas velocity shadow image (Figure 3). The letter *B* indicates the center of the vortex arising at the incident shock wave interaction with the front cloud surface.

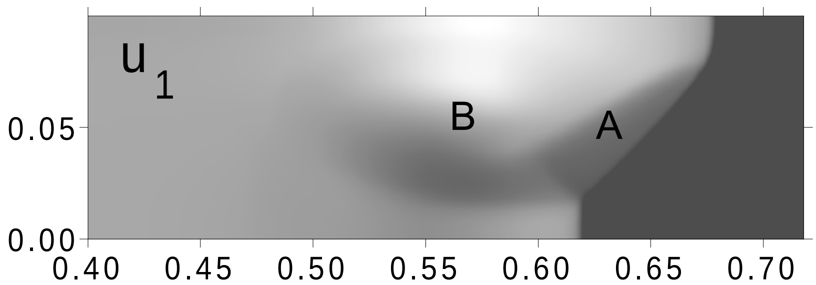

Figure 3. Gas velocity shadow image at 0.35 mc, M_0=3, d=5 μm.

The incident shock wave intensity increase makes the conditions for particle ignition and combustion zone arising. The developing of the process of combined shock/detonation wave propagation along the channel is plotted in Figure 4. The pressure shadow image shows the initial state ahead the shock wave as black, the state behind the incident shock wave in gas as grey and the region of high pressure values behind the detonation front in the cloud as white.

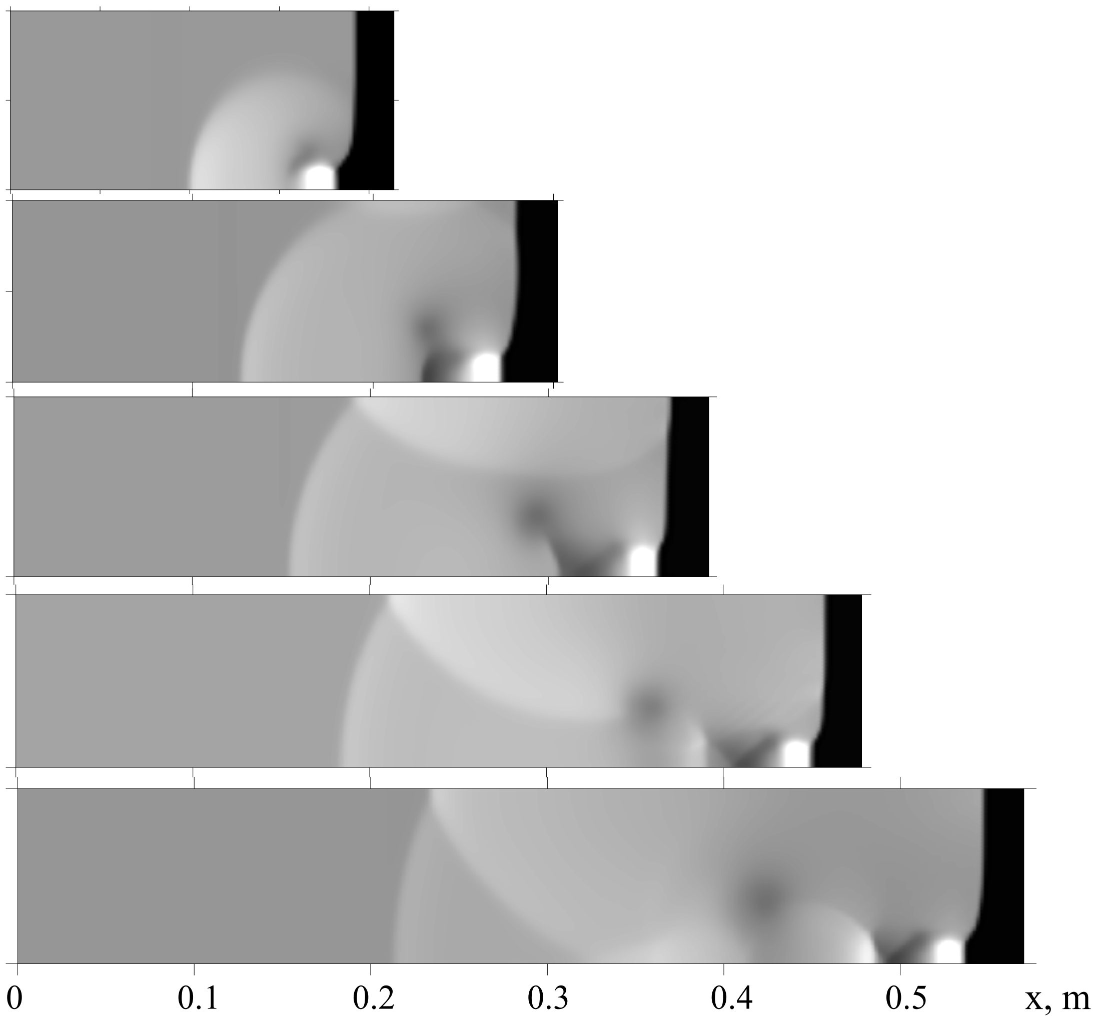

Figure 4.Shock&detonation wave propagation along the channel,
Δt= 0.05 mc, M_0=5, d=5 μm.

The bow-shaped shock wave bounds the light grey zone in Fig. 4. It arises as the result of the combustion zone appearing and joins with the shock wave reflected from the cloud front surface. This wave is more intensive then the reflected shock wave in the mixture of inert particles at the same conditions and its action affect the leading shock wave shape and propagation velocity outside the cloud. The transversal shock propagation and reflections both from the rigid wall and from the plane of symmetry leads to the leading shock wave fluctuation. Thus, the front acceleration outside the cloud occurs as the detonation front develops. The transversal wave action to the zone of detonation products behind the combustion front (dark spot near the line of symmetry) causes the pressure increase in this zone. The inclined shock wave arizen as a result of compression wave overturning is weakening and then intensifies again after the transversal shock wave reflection from the plane of symmetry. The transversal wave action generates also the detonation front fluctuations in the cloud and the pressure maximal value zone periodic migration from the plane of symmetry to the cloud surface and back.

Thus, the shock wave in gas joining with the wave of heterogeneous detonation in the particle cloud propagates in quasistationary regime. If the incident shock wave is supported and characterized by rectangular profile then the time average propagation velocity corresponds to strong stationary detonation regime.

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References.

1. Fedorov A.V., Fomin V.M., Khmel’ T.A. Non-equilibrium model of steady detonations in aluminum particle-oxygen suspensions// Shock Waves, 1999, V. 9, N 5, p. 313-318.
2. Fedorov A.V., Khmel’ T.A. Problem of detonation excitation in unbounded and bounded clouds of aluminum aerosuspension //Proceedings of the Third International Symposium on Hazards, Prevention, and Mitigation of Industrial Explosions, Tsukuba, Japan, October 23-27, 2000. P. 144-153.