Promotion of Secondary Combustion Phenomena by Geometrical Constrains in the Course of Non-Ideal Explosions.

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Until recently the main attention was paid to the consequences of primary interaction of products of a detonation of HE charge with an environment (air) and constructive elements. Such approach to an estimation of explosion consequences does not cause objections for so-called "ideal" HE (IHE), for which in detonation reaction zone the complete transformation of initial substance into combustion products such as CO_2, H_2O takes place. However, even for standard explosive compositions such as TNT [1-3], PETN [4] last assumptions are not exact. Special tests [1-4] show, that the products of TNT detonation contain such substances as CO, H_2, NH_3, C and the energy, released at detonation, Q_d = 1093 cal/g is significantly lower, than the energy Q_Σ = 3500 cal/g at complete after-burning of the products to H_2O and CO_2 [1,3]. Corresponding process of explosion transformation can result that the value $\Delta Q = Q_\Sigma - Q_d$ can be returned in system at late stages of expansion of explosion products and their mixing with air. The experiments [1-3] showed, that the additional energy release from after-burning products of detonation is promoted by realization of explosions in the enclosures, at reflection of primary explosive waves from obstacles, at enrichment of surrounding atmosphere by oxygen or other oxidizer.

Not enough attention was given to processes of secondary after-burning as well as their power and thermal loads up to date. Basic interest was mainly concentrated on determination of parameters of a primary explosive wave formed only at the expansion of detonation products without the taking into account of an opportunity of after-burning. Really, the phenomena of secondary after-burning in view of their significant delay in time from the initial act of a detonation do not influence parameters of an initial explosive wave, is especially at explosion in open space. However, the effect of secondary after-burning is rather essential for the estimation of mechanical and thermal action of explosion in the limited space or in the half-closed space in view of basic change of character of force loading on a constructive elements. According [1, 2, 4] the change of loading is shown in increase of average pressure of products of explosion and in increase of temperature from burning down products of incomplete detonation transformation marked in [8].

Following [5,6] it is possible to call the explosive compositions involved into additional after-burning process, as non-ideal explosive substances (NIHE). NIHE include all mixed explosive structures, consisting from molecular HE (such as TNT, RDX, etc.) and metal particles (such as AL, Mg, etc.). The repeated tests establish the fact, that the characteristic time of burning of metal particles in a mixture with the products of detonation of molecular HE (for example with CO) is about tens microseconds [12]. It predetermines the small contribution of the appropriate chemical processes to the detonation and practically is not reflected in pressure and temperature in a zone of reaction of a detonation wave. However, as noted in [5,6,9] the influence of metal particles basically is shown to occur with essential delay behind a zone of reaction during of after-burning in products of incomplete transformation or at direct contact to oxygen of air.

The purpose of the tests and calculations performed in the frame of the current work is the analysis of the flowfield generated by NIHE explosions in the presence of geometrical constrains such as the cone reflectors. The given purpose assumes the search of the configuration mutual arrangement of NIHE charge and reflecting element ensuring the maximal influence on the basic parameters of shock (explosive) waves (intensity, duration, structure, impulse) in the course of explosion.

In previous works [11,13-14] it was shown that the presence of spatial restrictions causes such phenomena of shock waves propagation, as shock waves focusing, formation of localized areas with increased temperature and pressure, i.e. initiating centers. The existence of such centers in an atmosphere capable to chemical energy release can result in initiation of secondary processes of combustion, thus strengthening primary gasdynamics perturbations, or altering their structure. The basic problem in realization of such a scenario is the synchronization of the process of formation of the initiating center due to gasdynamics interaction in cumulating flows and the process of chemical energy release in unburned reactive environment.

In the tests conducted in EMRTC facility the source of substances capable to secondary burnout was the mixture of paste HE consisting of IPN, RDX, and flaked aluminum. As a source capable providing the formation of the initiating center the set of cone reflectors was used. Such reflectors control the zones with the increased pressure and temperature. The prospective scheme of the process can be outlined as follows.

On the initial stage of a phase **I** there is an initiation of HE charge. The HE detonation causes propagation of a spherical blast wave BW and expansion of detonation products.

The phase **II** of the process is characterized by blast wave (BW) arrival to the opening of the cone-shaped reflector. Inside a reflector the phenomenon of BW focusing takes place with the formation of complex gasdynamics structures. As was shown in [13-14], by result such the interaction will be formation of precursor reflected shock, which represents localized in space at the center of a reflector a powerful shock wave, followed by the main reflected shock wave as presented in Fig. 1.

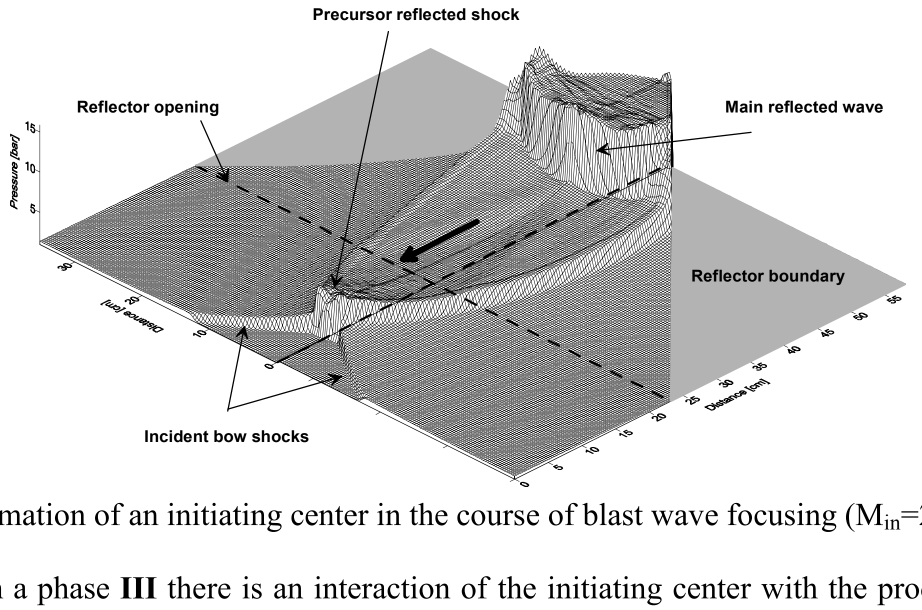

Fig. 1 Formation of an initiating center in the course of blast wave focusing (M_{in}=2, cone 90^0)

On a phase **III** there is an interaction of the initiating center with the products of HE detonation. The presence of a powerful shock-wave source consisting of an oxidizer (air), allows to assume an opportunity of initiation of secondary burnout in products of HE detonation provided that the moment of arrival of precursor wave is synchronized with the achievement of detonation products boundary nearby the cone opening.

The phase **IV** of the process is characterized by the propagation of secondary combustion front inside the cloud of detonation products. At this stage the secondary effects as secondary waves of pressure and general rise of temperature in a cloud of products are expected.

The basic obstacle for realization of the offered scheme of process is the synchronization of movement of a primary shock wave and the front of detonation products with parameters of a reflector at a stage of a phase **III**. The scheme of optimization of such script is represented in Fig. 2. It is obvious, that the shock wave should be rather intensive, that formed precursor shock wave had sufficient power for initiation of secondary combustion in detonation products, i.e. the charge weight should exceed the certain threshold on power. However, the fixing of power (weight) of a charge simultaneously firmly sets trajectories of the incident shock wave and contact surface movement, namely, border of detonation products. Thus, spatial temporary synchronization can be carried out by suitable selection of the geometrical characteristics of a reflector. It should be of rather large size to ensure the intensive reflected shock wave due to the scale factor. At the same time it must have appropriate height (the distance between apex and the opening) in order the incident shock wave has no opportunity to attenuate because of spherical symmetry.

The computations executed in the frame of the current investigations for an idealized HE charge with energetic equivalent 1 kg TNT for spherical geometry and cone reflector have shown, that optimal choice for realization of the described scheme is the explosion of 1 kg HE on distance 1.58 m from the cone opening with a corner 90^0 and and length 50 cm. Details of solution method and calculation scheme can be found in [13-14]

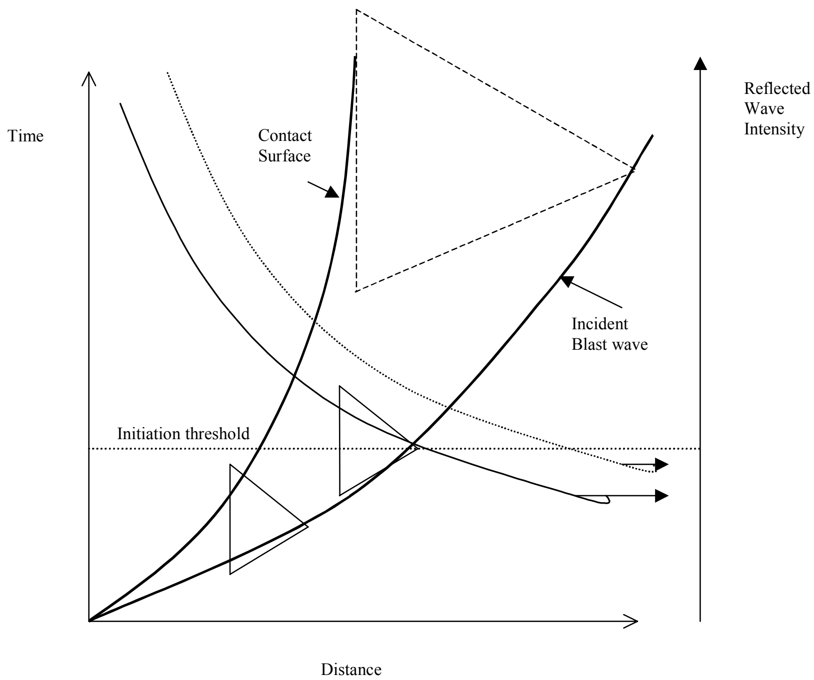

Fig. 2 Scheme of optimization of initiation procedure

The tests performed in EMRTC facility in Socorro NM USA permitted to establish experimentally the possibility to control the depth of secondary burn-out in NIHE products focusing process at cone reflectors. Experimental setup included the set of reflecting cones, placed at specially designed stand. The charge of HE was place at different distances from the cone openings thus providing to change synchronization time between focusing process and combustion products movement.

For visualization of the process of expansion of the explosion products two high-speed cameras ensuring registration from various directions were used. The sideview camera with frequency 8000 fps was placed on a ground surface perpendicular to the axis connecting the top of a reflector and HE charge at the distance approximately 15 m from a charge. The second overhead camera, with frequency of 10000 fps, was mounted above a reflector at height approximately 7 m from the surface of ground.

The results of the high-speed record with the help of the overhead camera are presented in Fig.3 for the case of charge detonation at the distance of 1.6 m from reflector. In the frames 1, 2 the detonation products front is seen before the cone. The additional region of the after-burning of the detonation products appears in the point “A” in frame 3 of the Fig. 3. Soon after that the combustion front (region “B” in frame 4) is formed. As it is seen in frames 4, 5 and 6 this front propagates from the cloud boundary to its center. For another distances of charge positions relative to the reflecting cone this pattern was not observed. This scenario is in qualitative accordance with the scheme of after-burning initiation process assumed. Moreover, experiments showed, that the distance between cone opening and charge position is the optimal distance the effect take place. Closer and far charge positions caused the weaker effect of reflector or lead to disappearing of the process of after-burning initiation.

Fig.4 presents the frame corresponding the time moment 1.6ms after charge detonation at the distance 1.4 m from larger cone reflector. The distance from the edge of the cone to center of the fireball is about 1.4m. This fireball is the source of additional energy release inside detonation products.

The work performed brings us to a conclusion, that placing specially chosen reflecting surface nearby the NIHE detonating charge can result in effect on the the process of after-burning in detonation products. The analysis presented shows the possibility of registration of this effect on the field of explosion. Established, that there exist effective distance, at which the secondary burn-out proceeds with the most completeness. This distance depends on the charge composition and the geometry of the reflector. For the standard HE (TNT-type) such dependencies were not found.

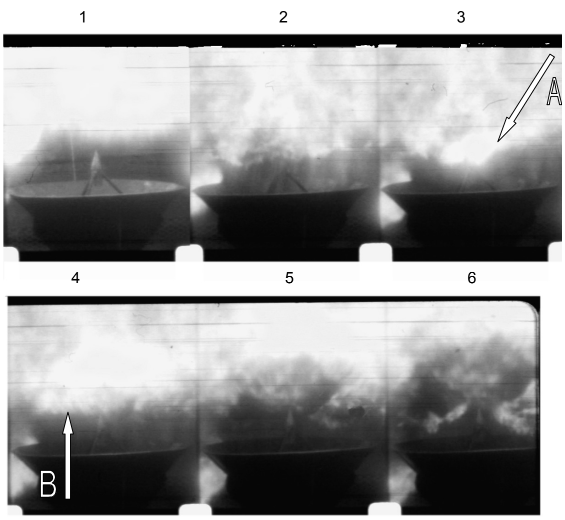

Fig. 3 Overhead camera frames for NIHE and cone reflector.
Distance between charge and cone 1.6 m.
Time between frames: 1-2; 200 µs, 2-3-4-5-6; 100 µs.

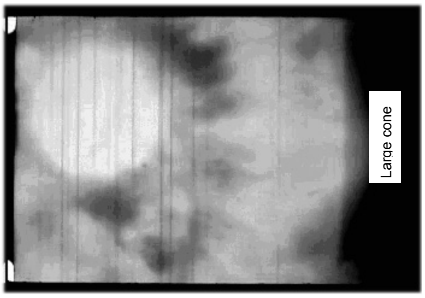

Fig. 4 Combustion fronts in detonation products of NIHE. Distance between charge and cone 1.4 m. Time: 1.6 ms after charge detonation.

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