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INITIATION OF DETONATION IN LOW-SENSITIVE EXPLOSIVES CONTAINING NANOPOWDER ADDITIVES BY HIGH VOLTAGE DISCHARGE

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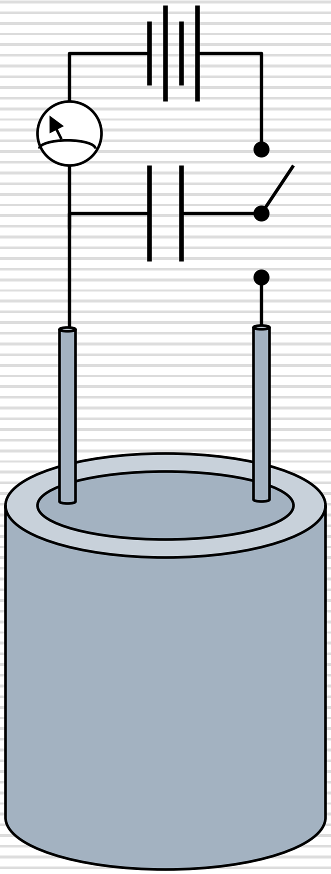
Experiments on high-voltage initiation of powder explosives



The powder explosives: PETN and FOX-7 (grain size of 3-7 μm).

The inert additives:

- copper nanopowder (particle size of 50-70 nm)
- aluminum nanopowder (50-70 nm);
- micron-size magnesium powder;
- copper powder with a particle size of ~ 50 microns;
- no additives.

Content of additive in the mixture: 10-25% by weight.

The density of mixture: 0.6-1.6 g/cm^3.

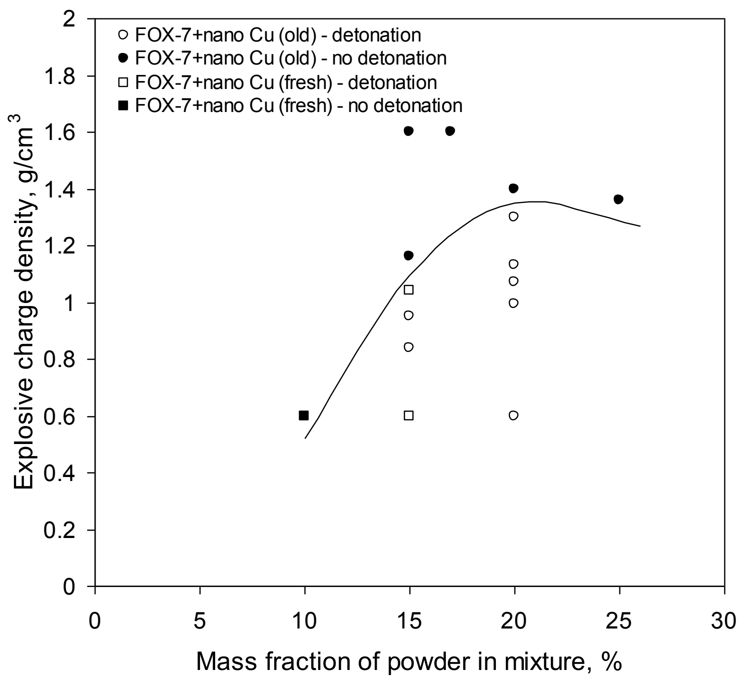
An inner diameter of vessel: 10 mm,

Two copper electrodes (diameter of 0.75 mm) at a distance of 4 mm from each other.

Initiation discharge device consists of a high-voltage power supply and capacitor of 1 μF, charged to a voltage of 7.5 - 9 kV.

The duration of the voltage pulse was ~1 ms.

Experimental data



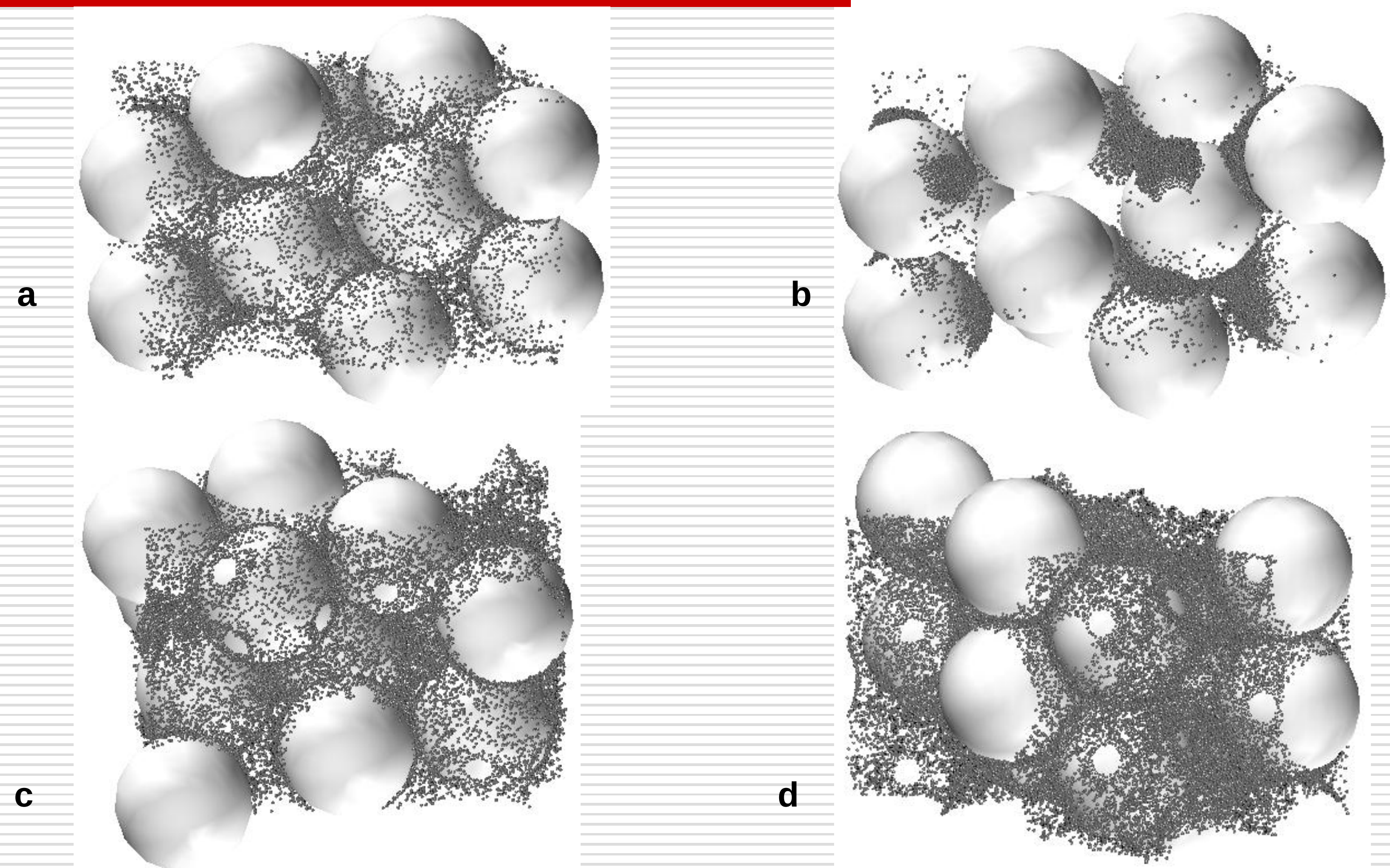
A detonation tooks place only in the mixture of FOX-7 with copper nanopowder and in the mixture of PETN with 15% of aluminum and copper nanopowders.

In all samples, in which the detonation was not observed, the fast combustion took place.

Conclusions:

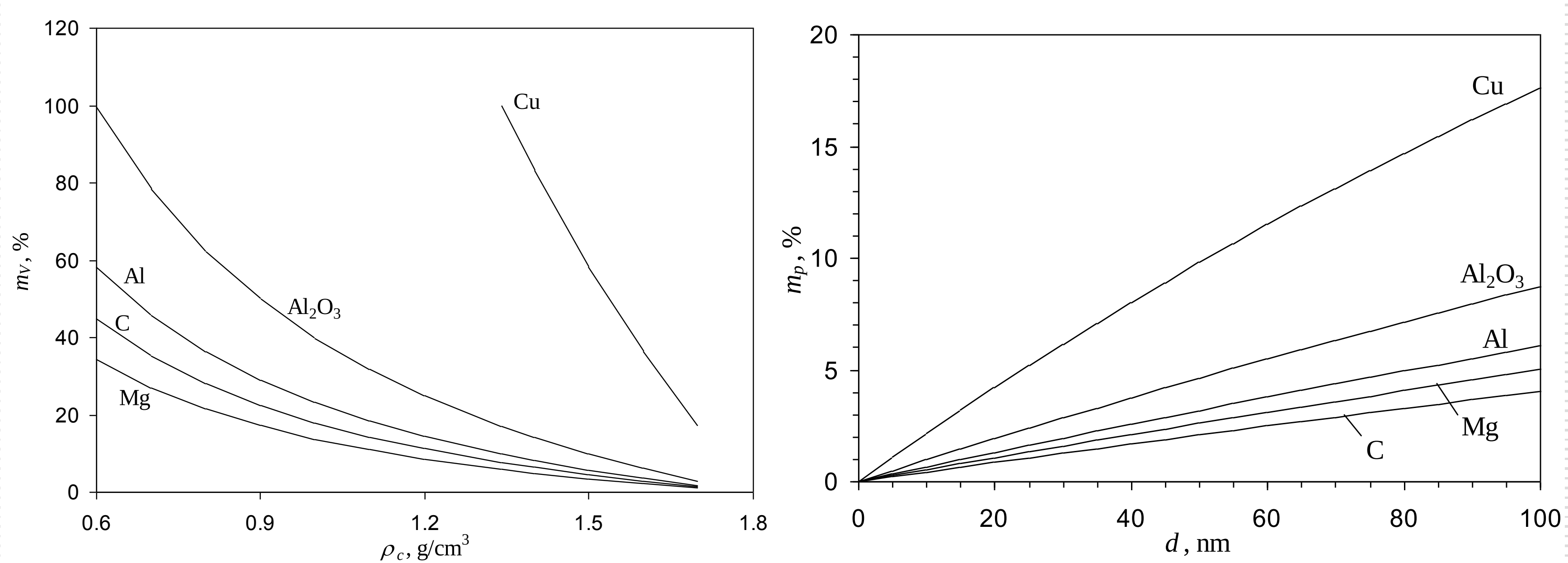
1. There is a critical size of inert particles, above which it is impossible to initiate a detonation in the given explosive.
2. Critical size is different for different powders of additive.
3. The limit of initiation of detonation depends on the explosive's nature.
4. There is a limiting concentration of nanopowder in the mixture for a fixed charge density, below which the detonation cannot be initiated.
5. There is a limiting charge density for a fixed concentration of nanopowder in the mixture, below which the detonation cannot be initiated.

Structure of explosive mixture



Particle sizes: D=3 mkm, d=70 nm. Volume concentrations: a, b – V_{exp}=0,59, V_{Cu}=0,01 (additive mass fraction m=7%), c – V_{exp}=0,58, V_{Cu}=0,02 (m=14%), d – V_{exp}=0,57, V_{Cu}=0,03 (m=19%); a, c, d – good blending, b – bad blending.

Percolate thresholds



Volume (left) and surface (right) percolate thresholds

Model of electrical breakdown

The conditions of electrical breakdown are equivalent to the conditions of occurrence of the thermal explosion in a chemical active system.

Percolate clusters form the channels of high conductivity between two electrodes.

When applied a voltage U to the electrode, the electric current begins to leak through the cluster.

The Joule heat is released and the temperature of the particles increases exponentially. After a new particle reaches the breakdown temperature threshold T_b, a new breakdown occurs and a drastic increase in temperature occurs in this nanoparticle.

This results in breakdown.

The Joule heat is equivalent to the heat released in chemical reactions, and the Arrhenius' temperature dependence of the conductivity of nanoparticle exposure is equivalent to the Arrhenius' temperature dependence of the chemical reaction rate.

That is, the electrical breakdown in a system of contacting nanoparticles propagates in the form of a wave in the relay-race mode, similarly to the propagation of the chemical reactions in powder mixtures, which is described by the thermal percolation model.

Thermal percolation combustion wave

The propagation velocity of the reaction along a system of identical hot-spots

$$u = \frac{\kappa}{d}\omega(\varepsilon)$$

$$\varepsilon = \left(T_b - T_0\right)/\left(T_{ad} - T_0\right)$$

$$T_{ad} = T_0 + Q_0 / cm_0$$

Exact solution for non-dimensional burning rate:

$$2\sqrt{\pi}\varepsilon = \sqrt{\omega}\sum_{k=1}^{\infty}\frac{1}{\sqrt{k}}\exp(-\omega k/4)$$

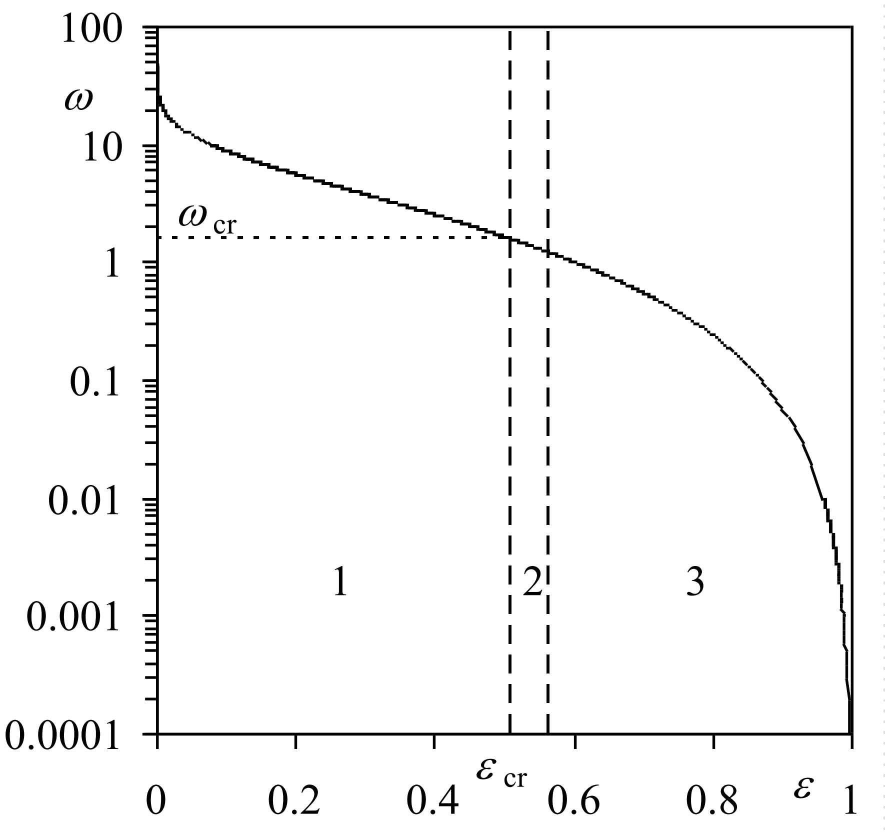


Figure. Dependence of non-dimensional velocity of burning wave on ignition temperature of hot-spots ε. 1- area of steady-state combustion; 2 – area of unstable combustion; 3 – area of extinction.
ε_{cr}=0.5115; ω_{cr}=1.573

Conditions of initiation of detonation

In order to initiate the detonation by a high-voltage discharge in a mixture of powder explosives with inert nanopowder, the following conditions should be satisfied:

- The surface percolation threshold should be reached.

$$m > m_p$$

- The velocity of breakdown propagation along the nanoparticle chain should be higher than the velocity of surface wave (Rayleigh wave) in explosive grains

$$u > a_s$$

$$\frac{\kappa}{d} > a_{ef} \equiv \frac{a_s}{\omega}$$

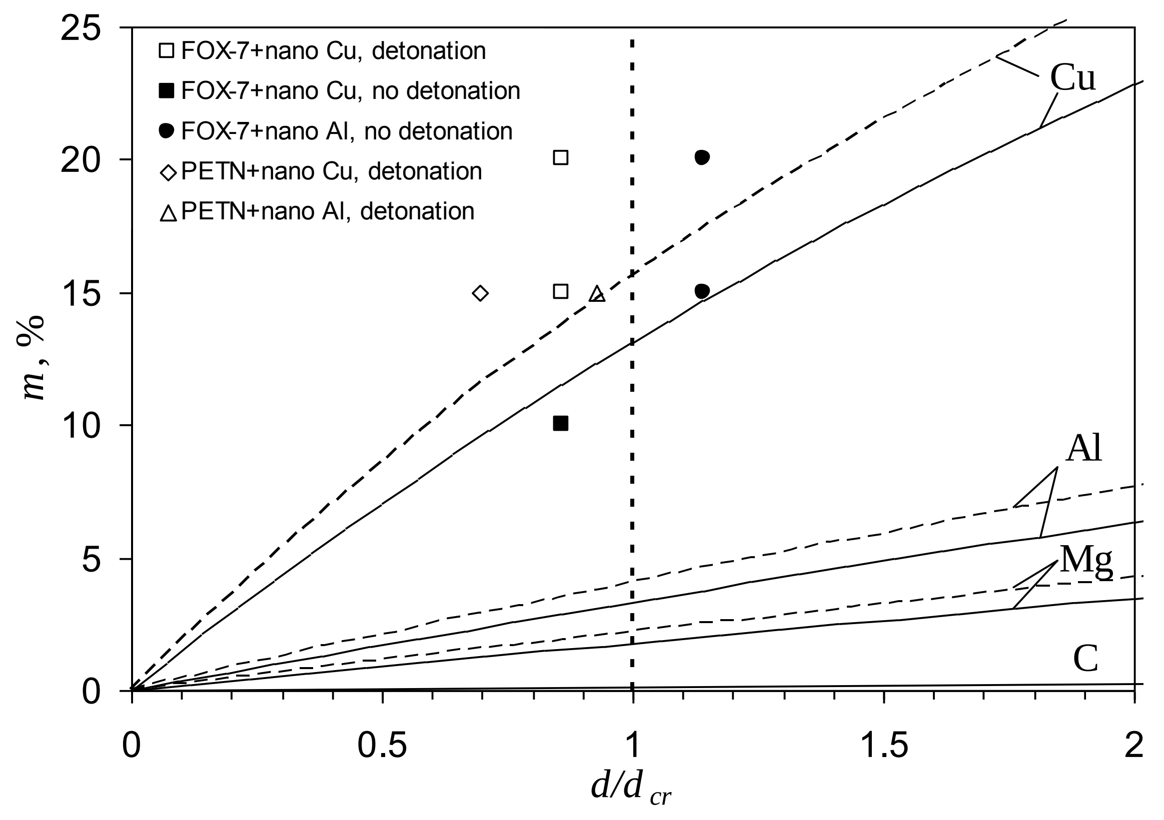
Thus, the diameter of nanoparticle should be more than a critical one

$$d < d_{cr} \equiv \frac{\kappa}{a_{ef}}$$

Properties of powders and their chains

Additive particle material	$a \times 10^4$, m^2/s	d_{cr}, nm at C_{Reff}=1300 m/s	d_{cr}, nm at C_{Reff}=1600 m/s	d_{cr}, nm at C_{Reff}=2000 m/s	Rate of thermal percolation *a*/*d* for different particle sizes, m/s		
					1 µm	100 nm	50 nm
Cu	1,12	86	70	56	112	1120	2240
Al	0,84	65	53	42	84	840	1680
Mg	0,68	52	43	34	68	680	1360
Al_2O_3	0,12	9,2	7,5	6	12	120	240
C	0,036	2,7	2,3	1,8	4	36	72

"Phase diagram" of initiation of detonation for mixtures of PETN and FOX-7 with different nanopowders.



Thank you for attention!