CONVECTIVE BURNING AND EXPLOSION IN THE MIXTURES BASED ON AMMONIUM NITRATE

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Abstract: Convective burning and burning-to-low-velocity-detonation transition in the loose-packed mixtures of ammonium nitrate with charcoal and aluminum have been investigated. The firings have been conducted in the closed bomb and cylinder casings with the samples which length was varied up to 600 mm. The maximum pressure–time derivative determined with the use of a pressure diagram recorded in the closed bomb has been selected as a measure of the burning activity of the samples being compared. It is shown that the value of this parameter changes in a wide range depending on fuel content, particle size of the mixture components, sample length, and pressure generated by igniter. With grinding ammonium nitrate, the burning activity increases but the dependence is nonmonotonous. All the tested mixtures with charcoal and majority of the mixtures with aluminum ASD-4 burnt out in the closed bomb with no explosion. Exception is the mixture of fine ammonium nitrate (20–40 μm) with 18% ASD-4. The burning of this mixture has ended with explosion which manifested itself by sharp fluctuations of pressure up to a few kilobars. The same explosions have been obtained with the mixtures composed of aluminum of the other mark PAP-2 and nanosized powder Alex. The firings in the cylinder casings have been conducted with the use of simultaneous photo- and piezorecordings in the mixtures based on fine ammonium nitrate. The sample length (up to 600 mm for the mixtures with charcoal and up to 300 mm for the mixtures with aluminum) seemed to be insufficient to reliably record the transition to a low-velocity detonation. However, the pressure records demonstrate the transition to a very fast pressure rise which originates with a delay behind the front of convective burning. It is accompanied by generation of a bright zone at the photorecord and can be classified as explosion. A clear photo of the burning-to-low-velocity-detonation transition with the run distance of 100 mm has been obtained for the mixture with nanosized aluminum. It apparently demonstrates the generation of the bright second wave behind the front of convective burning and emergency of low-velocity detonation after the second wave has caught up with the front. Dynamics of explosion in the mixtures with aluminum have been analyzed with the use of numerical modeling. The burning-to-low-velocity-detonation transition has been obtained numerically for the mixture of ammonium nitrate (particle size is 100 μm) with 8% aluminum (4 μm). The transition mechanism is related to vigorous heating of the mixture in the head of the compaction wave generated ahead of the front of convective burning. The key factor is the aluminum combustion. However, there is the dependence of the aluminum combustion rate on the concentration of oxidizing gases which enables us to offer explanations for the influence of grinding ammonium nitrate and changing aluminum content in the mixture on the dynamics of explosion.

Keywords: convective burning; low-velocity detonation; burning-to-detonation transition; explosion; piezoquartz pressure gauge; ammonium nitrite; aluminum; charcoal

DOI: 10.30826/CE20130209

Figure Captions

Figure 1 Pressure–time diagrams for burning of the mixture of ammonium nitrate (20–40 μm) and 4% charcoal in the closed bomb under various pressures produced by igniter: *1* — 13 MPa (no burning); *2* — 15 MPa (normal combustion); *3* — 18 MPa (convective burning, $W = 0.35$ m/s); *4* — 24 MPa (convective burning, $W = 0.6$ m/s); and *5* — 44 MPa (convective burning, $W = 2$ m/s)

Figure 2 Dependence of the minimal pressure for inducing the convective burning against charcoal content in the mixtures of ammonium nitrate of two fractions: *1* — fine fraction (20–40 μm); and *2* — medium fraction (250–630 μm)

Figure 3 Dependence of the maximal pressure rise rate against charcoal content for convective burning in the mixtures of ammonium nitrate. The particle size of ammonium nitrate: *1* — 20–40 μm; *2* — 250–630 μm; and *3* — 1–2 mm. The pressure generated by the igniter is 43 MPa

Figure 4 Comparison of the mixtures of ammonium nitrate of the medium fraction (250–630 μm) with charcoal (*1*) and aluminum ASD-4 (*2*) with regard to the dependence of the maximal pressure rise rate vs. equivalence ratio. Burning in the closed bomb, the pressure generated by the igniter is 43 MPa

Figure 5 Pressure diagrams recorded in the closed bomb during convective burning and explosion of the mixtures of ammonium nitrate (20–40 μm) with aluminum ASD-4 of the various content: 18% (*1*, explosion) and 31% (*2*, convective burning), the pressure generated by the igniter is 36 MPa; and with 18% aluminum PAP-2 (3, explosion), the pressure generated by igniter is 1.3 MPa

Figure 6 Photorecord (*a*) and pressure diagrams (*b*) demonstrating burning of the mixture of ammonium nitrate (230–650 μm) with 8% ASD-4 transitioned to explosion. The sample diameter is 10 mm, the length is 133 mm, initiation at the open butt end by a heating wire and 1.4-gram black powder. The distances of pressure gauges from the closed butt end: *1* — 200 mm; *2* — 71; and *3* — 0 mm

Figure 7 Pressure diagrams recorded during burning of the stoichiometric mixture of ammonium nitrate (1–2 mm) with 8.7% charcoal. The sample diameter is 10 mm, the length is 160 mm, initiation at the open butt end by a heating wire and 0.2-gram black powder. The distance of pressure gauges from the closed butt end: *1* — 200 mm; *2* — 71; and *3* — 0 mm

Figure 8 Pressure diagrams in 4 points along the casing demonstrating burning with explosion in the mixture of ammonium nitrate (20–40 μm) with 18% ASD-4 in the slit setup. The sample diameter is 10 mm, the length is 290 mm, ignition at the closed butt end. The distance to pressure gauges: *1* — 18 mm; *2* — 48; *3* — 108; and *4* — 208 mm

Figure 9 Pressure diagrams recorded during burning of the mixture of ammonium nitrate (20–40 μm) with 16% charcoal. The sample diameter is 10 mm, the length is 600 mm, initiation at the closed butt end by a heating wire and 1-gram black powder. The distance of pressure gauges from the closed butt end: *1* — 11 mm; *2* — 212; *3* — 282; *4* — 342 mm; *5* — 402 mm; and *6* — 485 mm

Figure 10 Photorecord demonstrating explosion in the mixture of fine ammonium nitrate (20–40 μm) with 18% aluminum Alex. The sample diameter is 10 mm, the length is 220 mm, ignition at the closed butt end by a heating wire with 0.1-gram black powder

Figure 11 Modeling results for the mixture of ammonium nitrate (400 μm) with 8% aluminum: (*a*) the flame front trajectories for ammonium nitrate (*1*) and aluminum (*2*); and (*b*) pressure above the open butt end (*3*) and maximum pressure (*4*)

Figure 12 Modeling results for the mixture of ammonium nitrate (400 μm) with 8% aluminum: profiles of main flow parameters at time 3.64 ms (*1* — pressure/(50 MPa); *2* — the condensed phase volume fraction; *3* — $U_k/(100$ m/s); *4* — $U_g/(100$ m/s); *5* — $T_g/(3000$ K); and *6* — Y_{ox}). The arrow indicates the flame front of convective burning

Figure 13 Modeling results for the mixture of ammonium nitrate (100 μm) with 8% aluminum: *1* — convective burning front, velocity 210 m/s; *2* — compaction wave, velocity 330 m/s; *3* — low-velocity detonation, velocity 1300 m/s; and black and gray curves — ignition of ammonium nitrate and aluminum, respectively

Figure 14 Modeling results for the mixture of ammonium nitrate (100 μm) with 8% aluminum: (*a*) evolution of pressure profiles; (*b*) evolution of condensed phase fraction profiles; *1* — 1.313 ms; *2* — 1.393; *3* — 1.472; *4* — 1.496; *5* — 1.50; *6* — 503; *7* — 1.514; and *8* — 1.528 ms

Acknowledgments

This work was supported by the subsidy given to the N. N. Semenov Federal Research Center for Chemical Physics of the Russian Academy of Sciences to implement the state assignment on the topics Nos. 0082-2016-0011 (Registration No. AAAA-A17-117040610346-5), 47.16 (AAAA-A20-120020590084-9), and 0082-2018-0004 (AAAA-A18-118031590088-8).

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Received May 14, 2020

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