A study of the combustion behaviors and mechanism of metal nitrates-based energy-saturated systems

Nguyen Duy Tuan

Relevance of work

It is known that inorganic nitrates of various metals are widely used in the composition of energy-saturated materials for various purposes. For example, KNO_3 is the main component of black powder and most aerosol-forming fuels for extinguishing fires. It is also, like $CsNO_3$, used in propellants for magnetohydrodynamic generators, which are capable of generating high electrical power. Alkali and alkaline earth metal nitrates are used in fireworks of various colours and in compositions that generate infrared interference.

Obviously, for the highly efficient use of energy-saturated systems based on inorganic nitrates, it is necessary to be able to purposefully control the process of their combustion. To do this, we need to know the behaviours and mechanism of combustion. Such data are available for black powder and NH_4NO_3-based systems. Since the 1990s, intensive works were begun on the development of aerosol-forming fuels based on KNO_3, and some results on their combustion was appeared. However, systematic studies of the combustion of numerous aerosol-forming fuels compositions have not been carried out, as well as systems based on nitrates of other metals.

Note that knowledge of the behaviours of combustion of these systems is also necessary to ensure the safety of their production, use, storage and transportation. In scientific terms, it is important to clarify the effect of the physicochemical properties of nitrates on the combustion of systems based on them and to clarify the features of the combustion behaviours in comparison with the combustion of ballistic powders, in which nitrogen oxides are the oxidizing agent.

Purposes and tasks of the work

The aim of the work were to study the behaviours and mechanism of combustion of metal nitrates-based energy-saturated systems (KNO_3, $NaNO_3$,

$CsNO_3$, $Ba(NO_3)_2$, $Sr(NO_3)_2$, $Pb(NO_3)_2$) in a wide pressure range from 0.1 to 18 MPa and to develop a fast-burning aerosol-forming fuels with a high fire extinguishing capacity.

To achieve these goals, the following tasks were solved:

- Calculation of thermodynamic properties of systems based on various nitrates;
- Investigation of the influence of pressure, oxidizer excess coefficient α and oxidizer particle size on the burning rate of the samples;
- Determination of the experimental combustion temperature of the samples;
- Determination of the temperature profile in the combustion wave of the samples to clarify the combustion mechanism;
- Investigation of the effect of aluminium and its alloy with magnesium on the burning rate of the samples;
- Study of the effect of catalysts, including in combination with soot and carbon nanotubes, on the combustion rate of systems;
- Development fast-burning AOT based on KNO_3 and its mixture with $KClO_4$.

Scientific novelty of the work

- for the first time in a wide pressure range (0.1-18 MPa) combustion behaviours of systems based on KNO_3, $NaNO_3$, $CsNO_3$, $Ba(NO_3)_2$, $Sr(NO_3)_2$, $Pb(NO_3)_2$ and the same fuel-binder (dibutyl phthalate-plasticized phenol-formaldehyde resin), which differ in the calculated combustion temperature due to a change in the excess coefficient of the oxidant (α) - were systematically studied. It is shown that at atmospheric pressure with a diameter of ~ 7 mm, only samples with a high value of α~0.9-1 do not burn.
- for most systems, there are two sections on the dependence of the burning rate on the pressure: in the first section, at low pressures, the value of n in the combustion law ($r_b=ap^n$) is significantly (2 or more times) less than in the second section.
- the dependence of burning rate on α is extreme.

- the experimental temperature of the combustion, depending on the value of α and pressure, may coincide with the calculated one, be higher or lower than it.
- mechanism systems are characterized by high temperature of the combustion surface (>1200K). The burning rate is determined in the k-phase, in which more than 79% of the heat required for the distribution of combustion is released.
- the size of the nitrate particles from 50 μm to 500 μm in the studied pressure range has a weak effect on the burning rate.
- the effect of aluminum (ASD-4) and an aluminium alloy with magnesium (PAM-4) on the burning rate of samples based on nitrates K, Na, Cs, Ba, Sr is complex and depends on the burning rate of a basic sample, cation nitrate, the nature of the metal, the amount and the dispersion, and the pressure at which combustion occurs.

Practical significance of the work

Fast-burning aerosol-forming fuels are proposed that have a high fire-extinguishing capacity (9.5-12 g/m^3), a burning rate was controlled over a wide range at atmospheric pressure (from 8 to 18 mm/s) and a low dependence on pressure in the range up to 1-2 MPa.