

THE INFLUENCE OF HEAT EXCHANGE PROCESSES ON THE COMBUSTION STABILITY OF ETHANOL AZIDE

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Abstract

The results of experimental and theoretical investigations of combustion process of ethanol azide (EA) into nonthermostatic tubes are presented. It was shown that the heat exchange between the wall of shell and liquid phase of ethanol azide leads to appearance of pulsating combustion. For the first time the transition to pulsating regime was observed with decrease of the external pressure. It was found the critical condition of transition from normal combustion of EA to pulsating regime.

Introduction

The ethanol azide (EA) are the organic azide. The study of organic azides combustion processes is of great interest to researchers. Such interest can be explained by the comparatively simple mechanism of chemical decomposition and the high burning rate of organic azides^{1,2} in comparison with nitroethers³. However, the too high values of organic azides burning rate make difficult the study of their combustion processes because these high values limit opportunities of experimental research methods. Therefore, for study of combustion processes of these substances it is convenient to have any organic azide with comparatively low velocity characteristics as an object for investigations. One of organic azides which meets these requirement is ethanol azide (EA). This organic compound burns steadily and relatively slow at the rate of $u=0,02\div0,2\text{cm/s}$ in comparatively wide range of pressure from 40 to 500gPa for tube diameter $d=0.6\text{cm}$. Besides according the conclusions of the Landau hydrodynamics theory⁴, the decrease of the burning rate value of any explosive must lead to the expansion of pressure range where the combustion proceeds in normal regime.

Experimental

The experiments have been carried out in the vacuum chamber (volume $4\cdot10^{-2}\text{m}^3$ at value of pressure below atmospheric one (from 13,3 to 1013gPa) in the air environment. The test samples of liquid EA were placed in nonthermostatic tubes of different materials (steel, copper, glass, celluloid). The main measurements have been conducted at the EA combustion in glass tubes (the thickness of wall $0,3\div0,5\text{mm}$ and height 40mm).

Results and discussion

One of the main results of the present study is the critical conditions of EA combustion in the nonthermostatic tubes from material with the different heat conductivity and the heat capacity. As the results of experiment have shown the fact of existence or absence of thermostatic shell for the EA charge greatly influences the combustion process and the critical conditions of EA combustion.

The critical conditions of EA combustion in the thermostatic tubes and the ones in the nonthermostatic tubes from glass are shown on the Figs.1 and 2, correspondingly. This critical conditions were obtained from the experimental data as the dependence of critical diameter of tube from the external pressure $d(p)$. In fact, the data shown on Fig.1 and Fig.2 prove that the critical conditions of EA combustion in the thermostatic tubes differ from those at the EA combustion in nonthermostatic tubes from glass. The interval of pressure at the EA combustion in thermostatic tubes may be divided into the following ranges: *I*-the zone where the combustion is not possible, *II*-the range of normal combustion, *III*-the range of turbulent combustion. The comparison of data from Fig.1 and Fig.2 has shown that at the combustion of EA in the nonthermostatic tubes from glass took place

the transition of normal combustion to pulsating regime. This transition takes place with decrease of the external pressure. On the contrary, such transition has not been observed in the case of EA combustion in the thermostatic glass tubes (Fig1).

Thus, we can make an assumption that the change of heatexchange conditions between the EA charge and the its shell leads to the breach of stability of the EA normal combustion and to the transition of it to pulsating regime. The possible reason of the transition of normal combustion to pulsating regime is the heat flux from the wall of shell to the charge of EA. This flux depends on the wall temperature which in its turn determines such factors as the burning temperature, the burning rate and the heatconductivity of wall material. The change of these parameters must influence the combustion process of EA. The experiments at the combustion of EA in the tubes made of different materials have been conducted. As the different materials were used the ones with heat conductivity higher (steel, copper) and lesser (celluloid) than for glass. As these experiments have been shown the character of EA combustion in such tubes is very different. The combustion of EA in the metal tubes has the explosive character. At the combustion of EA in celluloid tubes the pulsating regime wasn't observed and the EA burned in normal regime up to the values of pressure limited of zone **I** where the combustion process wasn't possible.

The theoretical analysis this phenomenon was conducted on the bases of Belyaev-Zeldovich's model of volatile explosives combustion³. In the model the heatexchange between the wall of tube and the liquid phase of EA was taken into account by us. The normal combustion of EA in this onedimension model was described approximately by the following stationary equation of heatconductivity:

$$\lambda \frac{d^2 T}{dx^2} - \rho u c \frac{dT}{dx} + F(T) - \alpha \frac{P}{S} (T - T_w) = 0$$

with boundary conditions in the coordinate which is connected with the boundary of phase transfer:

$$x = -\infty, \quad T = T_0; \quad x = 0, \quad T = T_s$$

here, **P** and **S** - the perimeter and the area of transverse section of tube; **F(T)** - the intensity of heat generation of chemical reaction per unit volume; **α** - the heatexchange factor (liquid phase of EA - wall); **T_w** - the temperature of tube wall; **x** - coordinate.

The solution of heatconductivity equation allowed to obtain critical condition of transition from normal combustion of EA to pulsating regime:

$$d = \frac{2a}{u} \sqrt{\frac{Nu (T_w^s - T_s) a_w}{(T_s - T_0) a}}$$

here, **d**-critical diameter of normal combustion, **Nu**-Nusselt's criterion, **a_w**-the thermometric conductivity of wall, **a**-the thermometric conductivity of EA, **u**-the linear burning rate, **T_s**-the surface temperature of EA liquid phase, **T_w^s**-wall temperature on the boundary of phase transfer.

This result is in good agreement with the experimental data. It can be seen from the critical condition the existence of transition from the normal combustion of EA to the pulsating regime depends to a great extent on the wall temperature **T_w^s**. If **T_w^s = T_s**, then critical diameter **d=0**. If **T_w^s < T_s** then the transition to the pulsating regime is not possible. Such conclusion was confirmed by the results of experiments⁵, when the combustion of EA occurred in the thermostatic tubes (Fig.1). Another conclusion is connected with the influence of the thermometric conductivity of wall material on the possibility of transition from the normal combustion of EA to the pulsating regime. Really, if **a_w** were increased, then the boundary of normal regime of EA combustion **d(p)** would move to the larger values of pressure (Fig.2). The zone **II** of normal combustion would become the narrow one. It may be expected that at large values of wall thermometric conductivity **a_w** stationary combustion of EA would not have been possible into such tubes. Just that was observed in the experiment for the combustion of EA into nonthermostatic tubes from metals. On the contrary, if **a_w** were decreased, then the boundary of normal regime of EA combustion **d(p)** would move to smaller values of pressure (Fig.2) and the zone **II** of normal combustion would become wider on account of the narrowing zone of pulsating regime. It was confirmed also by the results of experiments for the EA combustion into the celluloid tubes.

Thus, the conclusions obtained from the analysis of critical condition of transition from normal combustion of EA to pulsating regime are in good agreement with the experimentally observed results.

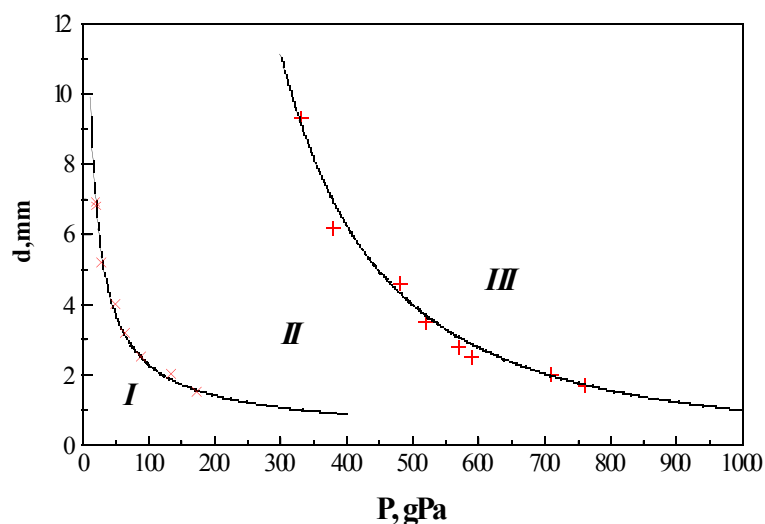


Fig.1 The critical conditions of EA combustion into thermostatic tubes.

I - the zone where combustion is not possible, *II* - the range of normal combustion, *III* - the range of turbulent combustion.

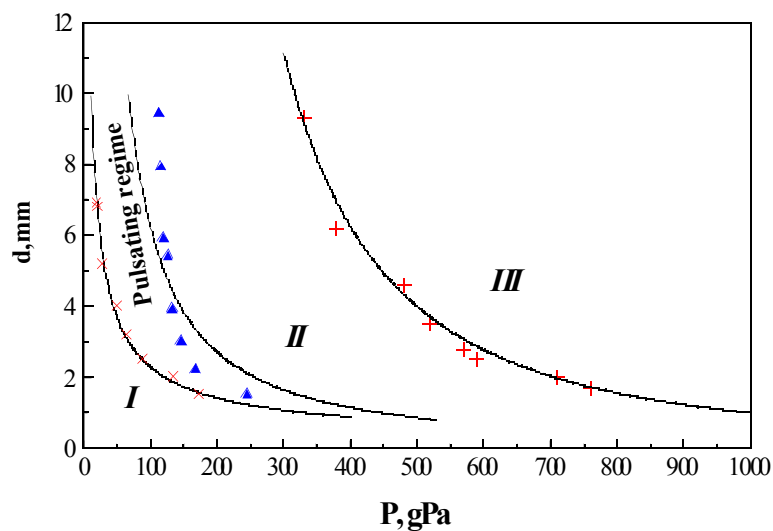


Fig.2 The critical conditions of EA combustion into nonthermostatic tubes.

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