Non-one-dimensional combustion modes of solid homogeneous energetic materials

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When modeling the combustion of solid homogeneous energetic materials (SHEMs), it is assumed that the combustion process is stationary, the burning surface is flat, and the burning wave is one-dimensional. It is known from theoretical analysis that under certain conditions a one-dimensional stationary combustion of SHEM can lose its stability, as a result of which the burning wave becomes unsteady, and in some cases, even non-one-dimensional. In this paper we discuss the experimental data which demonstrate that combustion of SHEMs occurs in cellular-oscillating mode in wide range of pressure: at the micro level (of the order of 1-5 mm), the burning surface is always covered by cells that periodically appear, move along the burning surface and disappear. The size of the cells increases with decreasing pressure, while the frequency of their appearance and disappearance decreases. We show that in this mode, a carbonized skeleton is formed on the burning surface, consisting of products of incomplete decomposition of SHEM. This skeleton is associated with the burning surface and plays an important role in maintaining the cellular-oscillating mode of combustion of SHEMs. Experimental data show that radius of curvature of the burning surface within the cells is of order of the thickness of the thermal layer of condensed phase of SHEMs. This means that in modeling of combustion of SHEMs within each cell on the burning surface it is necessary to take into account the local curvature of the burning surface. We demonstrate experimental data that show that combustion, even at low pressures, can be stabilized and a practically flat combustion surface can be realized if it is irradiated with a heat flux from a radiation heater during combustion. We consider the theoretical and experimental data on combustion of SHEMs with curved burning surface. We show that according to theory, the burning rate depends on the curvature of the burning surface: with increasing curvature of the burning surface, the local burning rate decreases and combustion becomes impossible if the nondimensional radius of curvature (Michelson-Markstein criterion) of the burning surface becomes less than some critical value. We show that using dependence of the burning rate on curvature of the burning surface, it is possible to calculate the critical combustion diameter of various SHEMs. We compare the calculated critical combustion diameters of various SHEMs with the available experimental data and compare the predictions of this theory with the commonly accepted heat-losses-driven theory of the critical combustion diameter. We discuss the recent experimental studies of combustion of SHEMs with curved burning surface in a wide range of curvature of the burning surface and compare these experimental data with theoretical dependencies. In conclusion, we discuss the role of cellular-oscillating combustion in SHEM extinction at a fast pressure drop.

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