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THE INFLUENCE OF THE HEATING WAY ON THE REACTION FRONT PROPAGATION IN THE LAYER BETWEEN TWO INERT MATERIALS

Two ways of the surface heating for the problem of material joining using solid-phase synthesis are realized numerically: uniform heating and heating by disturbed source. It was revealed that the heating way could be the cause of different regimes of reaction propagation between inert materials. The heating method influences on the temperature fields and ignition time.

Keywords: *solid-phase conversion, material conjugation, exothermal reactions, combustion modes, thermophysical properties, reaction initiation, heat flux, temperature field.*

Introduction

One of the most serious problems which are encountered when materials are joining leads to an energy-intensive. Nowadays some technologies which demand the minimum energy consumption are developed; it is possible to refer self-propagating high temperature synthesis (SHS) to them with confidence.

Generally speaking, SHS is the propagation process of chemical reaction wave along reactant mixture to finally solid product or new material formation. Ones distinguish several types of technological processes using SHS. Directly, this work is closely linked to SHS-welding. Welding process, when the exothermal reaction propagates in a gap between two specimens that are to be joined, is called SHS-welding. This type of welding possesses a number of advantages in comparison with traditional approaches to connection of materials. Effectiveness of SHS processes associated with the use of chemical heat instead of constantly heating from an external source of heat. SHS processes are characterized by high values of temperatures and combustion rates, equipment design simplicity and high quality of products. However, some of these characteristics (high-speed heating, rapid course of the reaction, the large temperature gradients) make control of the process problematic in conditions of a field experiment. Therefore, the mathematical modeling has a great significance.

It is possible to apply various energy sources for the heating of sample surface and subsequent initiation of the reaction. For example, the ignition of condensed matter can be carried out by hot body, heat flux, convective flux etc. Detailed investigation of this problem is described in [1] for various situations. Laser heating is very popular for ignition organization in laboratory investigations and new material synthesis. As an example, the models describing selective laser sintering of some powder mixture are given in [2–4]. Advantages of this method of ignition consist in controllability of heat influence parameters and possibility of ignition site formation in required area of a sample. For explosive decomposition of heavy metal azides extensively used laser radiation [5, 6]. Many papers were devoted to laser assisted cutting.

In this paper the influence of heating method on the propagation of the reaction front in the layer between two different inert materials is considered.

The problem formulation

The problem of inert material conjugation using chemical reaction energy is considered in a Cartesian coordinate system in the following approximation. Specimen consists of three layers of materials contacting ideally between each other. Middle layer is occupied by reagent.

Let assume that connection materials are inert and they have different thermophysical properties; the reaction mixture layer is between them. The properties do not depend on the temperature and composition. The chemical reactions are described by summary reaction scheme. In this work we use two ways of the heating.

In the first case, the sample is heated uniformly from the left side (Fig. 1, *a*). In the second case, heat flux is distributed along the surface corresponding to given law (Fig. 1, *b*). The others surfaces of the sample are adiabatically insulated.

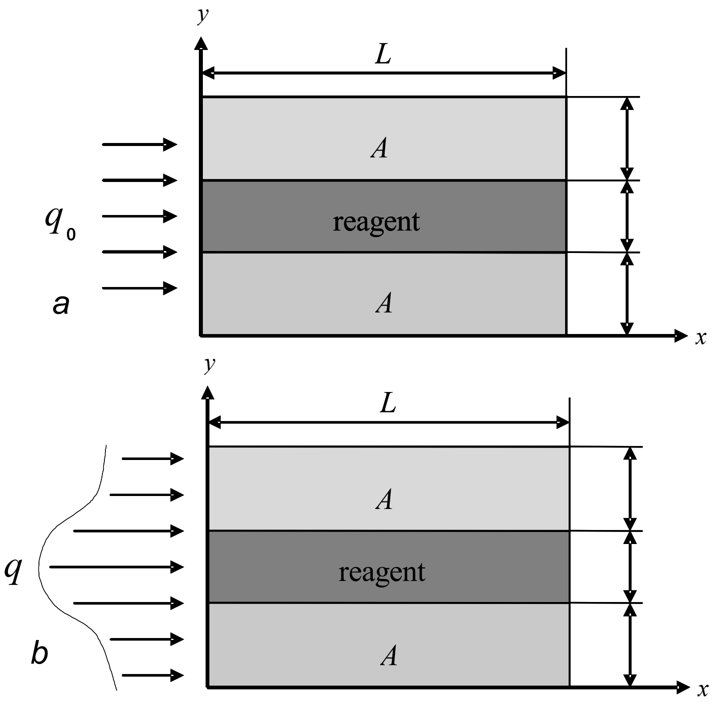

Fig. 1. The illustration to problem formulation.

To decrease a number of variables and an amount of necessary numerical calculations we solve the problem in dimensionless form. For transfer to dimensionless variables combustion problems typical scales of combustion theory were used. The detailed mathematical formulation of the problem is given in [7]. Here we indicate only special boundary conditions, reflecting the heating way.

In the case of uniform heating the condition in the point $\xi = 0$ takes the form:

$$\xi = 0: -K_{\lambda A}\frac{\partial\theta_A}{\partial\xi} = 1,\ \ -\frac{\partial\theta}{\partial\xi} = 1,\ \ -K_{\lambda B}\frac{\partial\theta_B}{\partial\xi} = 1; \quad (1)$$

in the other case we have

$$\xi = 0:\ K_{\lambda A}\frac{\partial\theta_A}{\partial\xi} = \exp\left(-\frac{(\eta-\eta_0)^2}{R^2}\right),\ \ -\frac{\partial\theta}{\partial\xi} = \exp\left(-\frac{(\eta-\eta_0)^2}{R^2}\right),\ \ -K_{\lambda B}\frac{\partial\theta_B}{\partial\xi} = \exp\left(-\frac{(\eta-\eta_0)^2}{R^2}\right), \quad (2)$$

where ξ, η – dimensionless coordinates; $K_{\lambda A}$, $K_{\lambda B}$ – relative thermophysical properties of connecting materials; R – is effective radius of the source; η_0 – the point of the maximal heat release due to external heating.

Results and Discussion

Numerical realization of the model was implemented using non-explicit difference scheme, coordinate splitting and linear double-sweep method.

The influence of the heating way on the course of the reaction is demonstrated on the Figs. 2 and 3. On these figures, the darker areas correspond to the higher temperature. Reagent occupies the region between the lines and (they are not shown in the illustrations).

If thermal conductivity and heat capacity are the same for all substances (Fig. 2), we see, firstly, that in the case of nonuniformly distributed heat flux, the ignition process occurs later and, secondly, the temperature changes within a narrower range. The rapidity of the reaction is explained by the fact that the connecting materials accelerate the heating and promote reaction front propagation.

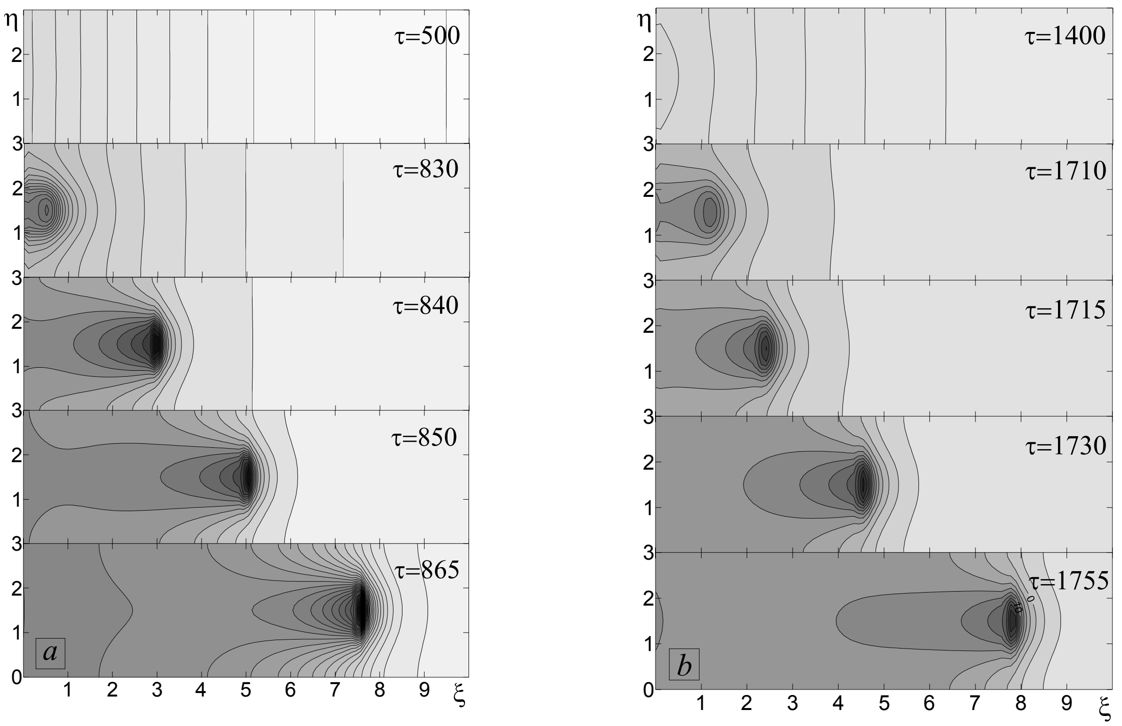

Fig. 2. Qualitative presentation of emperature fields in successive moments of time for parameters: $\theta_0 = 10$; $\beta = 0.03$; $\gamma = 0.03$; $\mathrm{Fr} = 20$; $R = 1$; $K_{\lambda A} = K_{\lambda B} = K_{cA} = K_{cB} = 1$; *a* – boundary conditions (1), *b* – boundary conditions (2).

When the reaction takes place between materials with the high heat capacity, temperature fields for two types of the boundary conditions have qualitative feature only near the boundary (Fig. 3). Similarly to the previous case, the reaction initiated with the help of distributed heat flux has a lower temperature maximum, however, for given parameters, the processes evolution over time qualitatively identical for both methods.

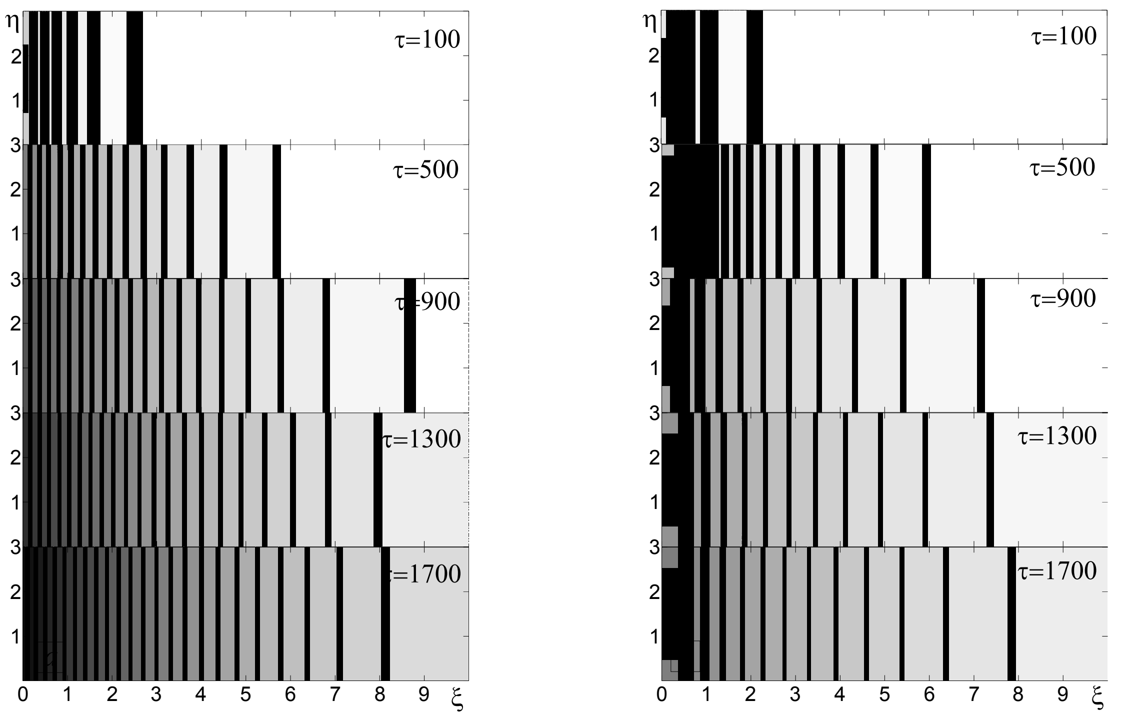

Fig. 3. Temperature fields qualitative presentation in consequent moments of time for parameters: $\theta_0 = 10$; $\beta = 0.03$; $\gamma = 0.03$; $\mathrm{Fr} = 20$; $R = 1$; $K_{\lambda A} = K_{\lambda B} = 1$; $K_{cA} = K_{cB} = 5$; *a* – boundary conditions, described with help of formula (1), *b* – boundary conditions, described with help of formula (2).

Conclusions

In this work stationary two methods of reaction initiation were described. It was shown that if it is important to reduce the temperature combustion of considered system, in that case it is advisable to use a heat flux, which maximum is concentrated in the region occupied by the reacting substance. Also it have been shown, that the influence of initiation method on the reaction course in the case of high heat capacity of connecting materials is insignificant.

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