MATHEMATICAL MODELLING OF HEAT AND MASS TRANSFER AT THE IGNITION OF A LIQUID CONDENSED SUBSTANCE BY A LOCAL SOURCE WITH LIMITED ENERGY CAPACITY

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МАТЕМАТИЧЕСКОЕ МОДЕЛИРОВАНИЕ ПРОЦЕССОВ ТЕПЛОМАССОПЕРЕНОСА ПРИ ЗАЖИГАНИИ ЖИДКОГО КОНДЕНСИРОВАННОГО ВЕЩЕСТВА ЛОКАЛЬНЫМ ИСТОЧНИКОМ ОГРАНИЧЕННОЙ ЭНЕРГОЕМКОСТИ

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Выполнено численное исследование процессов тепломассопереноса при зажигании жидкого конденсированного вещества типичным погружающимся источником ограниченной энергоемкости – нагретой до высоких температур металлической частицей малых размеров. Исследования проведены при помощи математической модели, учитывающей группу взаимосвязанных физико-химических процессов (теплопроводность, диффузия, конвекция, радиационный теплообмен) с фазовыми переходами (испарение жидкости, кристаллизация материала частицы). Установлены предельные характеристики источника энергии, достаточные для воспламенения конденсированного вещества.

The processes of heat and mass transfer were studied in the system «liquid condensed substance – energy source – air». As a local heat source with limited energy capacity, we examined a high-temperature metallic (steel) particle of small sizes. Mathematical modeling of heat and mass transfer processes at the ignition of a liquid is made for a typical condensed substance (CS) with well-known thermophysical and thermochemical characteristics: kerosene.

It was assumed that a hot particle deposited slowly (at 0.5 m/s) on the surface of a liquid CS and immersed into it. Different conditions of immersion of the particle, involving the formation of a vapor gap between energy source and liquid during the ignition delay time were examined. It was taken into account that the liquid warms up as energy is supplied from a local heat source. The conditions of vapor formation were reached near the frontal and lateral surfaces of the particle. In these areas the evaporation process of liquid begins. As a consequence, there emerges a vapor gap between the immersed source and the liquid. The vapor is injected into the oxidant (air) and mixed with it due to diffusion and convection. There arises a vapor-gas mixture. It includes initial component (oxidant) and vapors of water and combustible, involved in a chemical reaction. When terminal conditions were reached (for the concentration of combustible and for the temperature of vapor-gas mixture) the process of oxidation accelerates and becomes irreversible, thereby causing ignition.

In our numerical modeling, we used two ignition criteria, considering in the most complete manner the macroscopic features of heat and mass transfer processes:

1. The heat emerging due to the chemical reaction of oxidation of combustible vapors in the air is greater than the heat transferred from the energy source to the liquid CS and vapor-gas mixture.

2. The temperature of the mixture of the CS vapors and the oxidant is higher than the initial temperature of the heat source.

Mathematical modeling of heat and mass transfer processes at liquid CS ignition reduces to the solution of a set of non-linear non-stationary differential equations with partial derivatives (analog [1, 2]): the continuity equation, the equation of motion, the energy equation, the diffusion equation, the balance equation, the heat transfer equation.

The set of equations was solved by the method of finite differences. Besides, we solve difference analogues of the differential equations by the locally one-dimensional method. The equations of elliptic type (continuity and motion) were solved by using the method of alternating directions. In order to solve one-dimensional difference equations, we used the sweep method with an implicit four-point scheme. Non-linear equations were solved by the iteration method. In order to increase the accuracy of solutions of the set of differential equations we select no less that 400 knots of the difference net for each of the coordinates (near the borders of phase transition the difference net is made denser) and use time step 10^{-6} s.

The reliability of the obtained results has been verified by the comparison with the experimental data. Testing of numerical methods and elements of algorithm for differential equations system decision with corresponding initial and boundary conditions is carried out on the example of nonlinear processes of heat conductivity and chemical kinetics. Besides check of the energy conservation law in the solution field was carried out. The error of the energy conservation law at change of initial temperature and the rates of a hot particle did not exceed 2.5%.

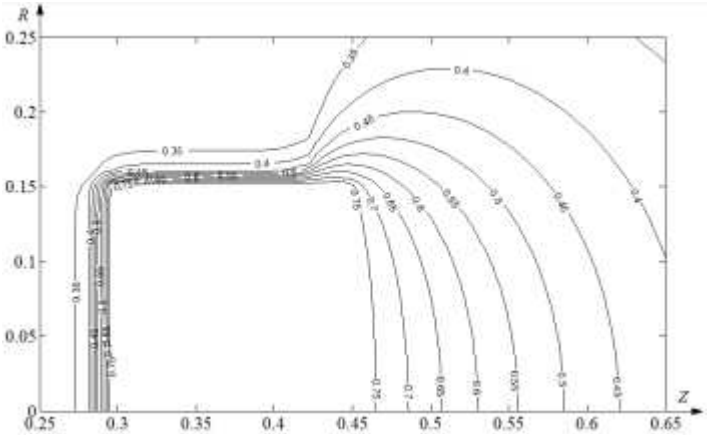

Fig. 1. Isotherms (Θ) of the system «liquid CS – metallic particle – air» at the complete immersion of the particle (τ=3, Θ_p=0.85, R_p=0.15, Z_p=0.15)

As a result of numerical research in the system «liquid CS – metallic particle – air» we get isotherms (Fig. 1) and dependences of the ignition delay time on local energy source parameters (Fig. 2).

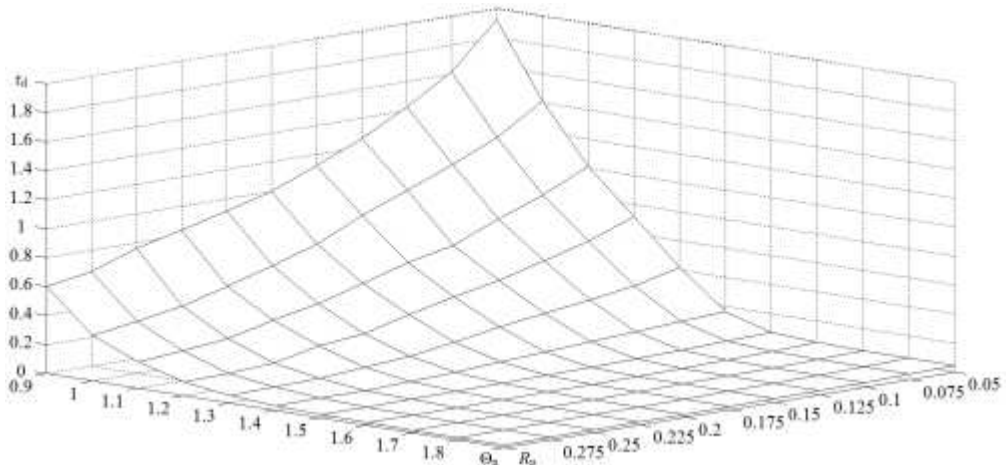

Fig. 2. The dependence of the ignition time delay τ_d on Θ_p and R_p

Fig. 2 shows the surface $\tau_d=\tau(R_p, \Theta_p)$ that symbolically separates the regions of inflammation (below the

surface) and non-inflammation (above the surface).

We indicate the terminal values of the basic parameters (temperature, sizes) of a hot particle that permit inflammation. Thus, for instance, it has been discovered that in the system under consideration the temperature Θ_p=0.9 (at R_p=0.15 and Z_p=0.15) is the low boundary of the range of temperatures of a particle that permit the inflammation of a liquid CS. We have also established, both experimentally and numerically, a similar boundary for the range of the particle's sizes at a fixed temperature. Thus, for instance, at Θ_p=1 ignition occurs only at $R_p \geq 0.05$ and $Z_p \geq 0.15$. The previous study determined the configurations of energy sources for which the durations of delay are minimal (particles shaped as a parallelepiped), and for which the processes of ignition are characterized by the maximal sluggishness (particles shaped as spheres and hemispheres). The statement of the problem of heat and mass transfer with particles shaped as cylindrical disks is specified by average values of the integral characteristics of ignition in comparison with particles shaped as a parallelepiped or a sphere. Consequently, in the model under consideration the dependencies of τ_d on Θ_p and R_p (Fig. 2) characterize the upper and lower estimations of the ignition time delay for systems of particles shaped as a parallelepiped and a sphere, respectively.

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МОДЕЛИРОВАНИЕ ЭЛЕКТРИЧЕСКОЙ АКТИВНОСТИ СЕРДЦА ИСПОЛЬЗУЯ ЭЛЕКТРОКАРДИОГРАФ НА НАНОСЕНСОРАХ

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COMPUTER SIMULATION CARDIAC ELECTRICAL ACTIVITY USING AN ELECTROCARDIOGRAPH ON NANOSENSORS

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This article describes the issues related to cardiovascular disease. A method is proposed to address this issue. We consider a Aliyev - Ponfilov model. The algorithm of hardware-software complex. Presents the conclusions.