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ENAEE ECTN КАЗФОСФАТ ARALSODA БГТУ

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SOFTWARE DEVELOPMENT (SOFTWARE ENGINEERING

$$\|u\|_{C([0,T],L_2[-l,l])} \le M(\delta,\sigma,\beta,l)\left[\|\varphi\|_{L_2[-l,l]} + \|f\|_{C([0,T],L_2[-l,l])}\right]$$

and coercive stability estimates

$$\|u_t\|_{C^{\alpha}_{0}([0,T],l_2[-l,l])} + \|u_{xx}\|_{C^{\alpha}_{0}([0,T],l_2[-l,l])} \le M(\delta,\sigma,\alpha,\beta,l)\left[\|\varphi_{xx}\|_{l_2[-l,l]} + \|f\|_{C^{\alpha}_{0}([0,T],l_2[-l,l])}\right]$$

hold.

The proofs of theorem based on the following abstract theorem on stability of problem (3) in C([0, T], E) space and coercive stability in $C^{\alpha}([0,T],E)$ and $C^{\alpha}([0,T],E)$ spaces and on self-adjointness and positive definite of the unbounded operator $A = A^x$ defined by formula (2) in $L_2[-1,1]$ space.

Theorem 2. [3] Let A be strongly positive operator in a Banach space E and $f \in C^{\alpha}([0,T],E)$ $(0 < \alpha < 1)$. Then, for the solution of the initial value problem (3) the stability and coercive stability inequalities

$$\|u\|_{C([0,T],E)} \le M\left[\|\varphi\|_E + \|f\|_{C([0,T],E)}\right],$$

$$\|u'\|_{C^{\alpha}_{0}([0,T],E)} + \|A_u\|_{C^{\alpha}_{0}([0,T],E)} \le M\left[\|A_{\varphi}\|_E + \frac{1}{\alpha(1-\alpha)}\|f\|_{C^{\alpha}_{0}([0,T],E)}\right]$$

hold. Moreover, assume that $A\varphi - f(0) = 0$ and $f \in C^{\alpha}([0,T],E)$ $(0 < \alpha < 1)$. Then, for the solution of the initial value problem (3) the coercive stability in-equality

$$\|u'\|_{C^{\alpha}([0,T],E)} + \|Au\|_{C^{\alpha}([0,T],E)} \le \frac{M}{\alpha(1-\alpha)}\|f\|_{C^{\alpha}([0,T],E)}$$

holds.

In the next theorem, the self-adjointness and positive definiteness of the operator $A = A^x$ defined by formula (2) in $L_2[-l,l]$ space will be studied.

Theorem 3. Assume that $\delta - a|\beta| \ge 0$. Then the operator $A = A^x$ defined by formula (2) is the self-adjoint and positive definite operator in $L_2[-l,l]$ space with the spectral angle $\varphi(A,H) = 0$.

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EFFECT OF SUPERSONIC FLOW TEMPERATURE ON THE DIFFUSION COMBUSTION OF HYDROGEN

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Abstract: The results of numerical and experimental studies of the influence of temperature and supersonic flow composition on the hydrogen combustion kinetics are presented for a coaxial fuel and oxidizer feed. Depending on mode parameters of the supersonic flow the process is shown to occur with an intense heat release limited first of ail by the velocity of chemical reactions, or diffusion combustion with heat release depending on the rate of fuel mixing with oxidizer realizes. Increase of stagnation temperature T_{02}>2500K produces inert behavior of diffusion combustion od non-mixed gases. According to the calculations intensive combustion increases the pressure to 11,4% in comparison with diffusion regime.

Keywords: Supersonic flow, hydrogen, combustion, numerical calculations, chemical reactions, temperature, coaxial stream, turbulence model.

INTRODUCTION

Combustion in the chamber at supersonic cocurrent input of the central hydrogen jet to the stream has its features [1-10]. As experiments showed [8-10], combustion becomes intensive in pseudo-shock mode. At present, one of the problems of study of combustiqn processes in jets is the draft loss of engine due to impairment of combustion process at the Mach numbers of the flight more than 8-10. In this case the temperature of the flow braking exceeds 2000K, heat input of combustion of fuel material is not sufficient, and "quiet" diffusion combustion takes place. Decrease of the period of ignition delay degrades the process of hydrogen mixing with air at initial zone of the flow, and limiting factor for combustion may be the process of fuel mixing with oxidizer. The given problem is studied below by the analysis of calculating data of the process in the combustion chamber at coaxial input of hydrogen jet in supersonic airflow.

MATHEMATICAL MODEL OF THE FLOW

Development of round supersonic jet of hydrogen in coaxial supersonic stream in the combustion chamber is considered. Cold hydrogen jet with the temperature T_1 flows to the hot air flow with the temperature T_2 and they mix. Let consider boundary layers on walls of the nozzle and combustion chamber very thin due to high gas velocities. Mixing area begins from the nozzle edge, reacting mix of gases is forming which self-ignites, and diffusion combustion of nonmixed gases of hydrogen jet and coaxial stream begins in the chamber.

The flow is supposed to be supersonic cylindrical chamber axis-direction, gas is considered as viscous, heat-conductive, chemically reacting, and the flow mode - as turbulent. For flow characterization the system of parabolized Navier - Stokes equations averaged by Reynolds is used [3,5,11,12]. Rate of hydrogen combustion in the air is characterized by multistage mechanism, including 18 chemical reactions, in which concentrations of eight active substances H, O, OH, H_2O, O_2, H_2, HO_2, H_2O_2 participate [13]. Nitrogen, which is present in the air, is inert and does not interact with other components of the mix.

Turbulent viscosity coefficient υ_t is found from (k-ε)-model turbulence for compressible flow [14].

Influence of turbulence on velocity of chemical reactions was considered using the model of unmixedness [15,16], which approximately defines damping influence of pulsations of substances concentration on the velocity of chemical reactions.

Boundary conditions of the equation system in initial section of jet and flow are set in the form of constant values of required variables. On the axis of combustion chamber conditions of symmetry are correct. Boundary conditions on the wall of combustion chamber are defined from conditions of reflection and rule of the wall [11,12]. Applying of the rule of the wall allows circumventing calculation of all thin near-wall area that considerably reduces required calculation time.

Equation system together with boundary conditions is solved by numerical method [11].

For verification of mathematical model and solution method experimental data of combustion of hydrogen round supersonic jet in coaxial supersonic stream [17] were used. Calculations were made at the following operating conditions of the jet (M_1=2.0, T_1=251K, $C^0_{H_2}$ =1.0) and the flow (M_2=1.9, T_2=1495K, $C^0_{H_2O}$ =0.281, $C^0_{O_2}$ =0.241, $C^0_{N_2}$ =0.478). Pressures of the jet and flow were equal (P_1=P_2) and off-design degree was equal (n=1). Fig.1 shows distributions of concentration of vapors of water, oxygen and nitrogen in the section x/d_1=8,76, where ignition of reacting mix takes place.

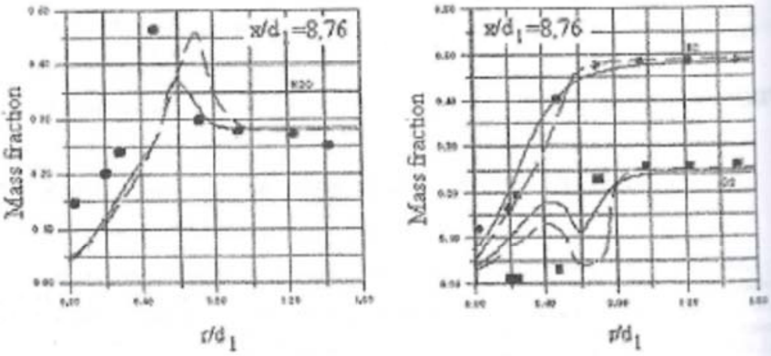

Fig. 1 – Distributions of concentration C_{H_2O}, C_{O_2} and C_{N_2}

(— calculations of the Authors; --- calculations [16], points - experiment [17])

Numerical calculations of concentrations of vapors of water C_{H_2O}, oxygen C_{O_2} and nitrogen C_{N_2} (see Fig. 1) illustrate ignition of reacting mix and coordinate with experimental and calculating data [16,17].

DISCUSSION OF CALCULATION RESULTS

On the Fig. 2 fields of concentration of radical OH and temperature T are given in operating conditions of hydrogen jet (M_1=1.4, T_1=251K, $C^0_{H_2}$=0.4, $C^0_{N_2}$=0.6) and airflow parameters (M_2=2.2, $C^0_{O_2}$=0.232, $C^0_{N_2}$=0.7679, C^0_{OH}=0.0001). Off-design degree of the jet was equal n=0.7. Stagnation temperatures of the flow were different: T_{02}=1920K for the cases (Fig. 2 a, c) and T_{02}=2500K – for the cases (Fig. 2 b, d).

At temperature value of the flow stagnation T_{02}=1920K self-ignition begins at the distance x/r_1=110 (r_1 – jet radius, r_1=1mm), and combustion practically ends at x/r_1=250. Self-Ignition takes place in paraxial zone of the jet, and general burning-out is observed in the same place (Fig. 2 a, c). Self-Ignition delay leads to sufficiently full mixing of hydrogen with air, and reacting mix is formed with heat and kinetic conditions for chemical reactions. In this case, calculation data of the field of concentration of radical OH and temperature T show that determining factor of diffusion combustion is the velocity of chemical reactions. Increase of the temperature of the flow stagnation T_{02}=2500K leads to that hydrogen self-ignites, beginning from the periphery of the jet (Fig. 2 b) and at the distance x/r_1=60. In high-temperature flow processes of dissociation begin to be very important. Additional activated radical OH appear (Fig. 2 b), in particular, after heat decay of molecules H_2O – end product of chemical reaction. Radicals OH produce early self-iginition of hydrogen. In the given regime decrease of the length of delay more than twice decreases the time of mixing of the jet and airflow. Therefore the process is limited by mixing (Fig. 2 d), and "quiet" diffusion combustion is realized. Calculation data are in qualitative accordance with the experiment [4,6].

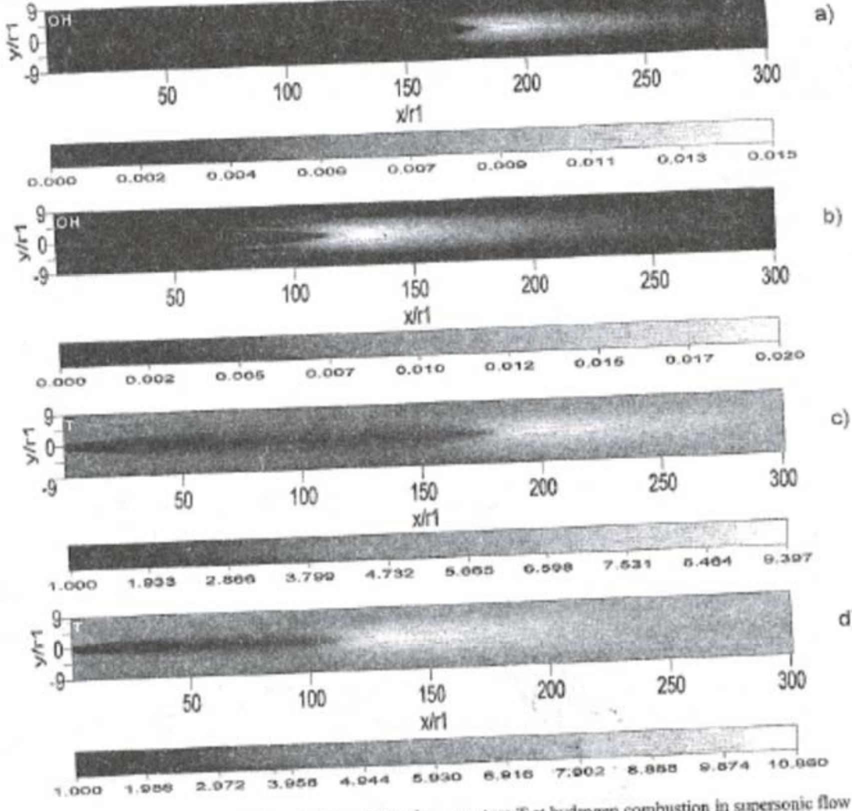

Fig. 2 – Fields of concentration of radical OH and temperature T at hydrogen combustion in supersonic flow

Different characters of combustion of no mixed gases lead to difference of growth of pressure along the length of chamber of combustion. Calculation data of relation of statically wall pressure of chamber on pressure of stagnation of flow are shown on Fig. 3. Delay of ignition leads to constant pressure till x/r_1=100 and then to beginning of monotonous growth (Fig. 3, curve 1). Waves of disturbance lead to appearance of zones of compression and rarefaction and to oscillation of pressure over the wall because of heat release from chemical reactions. With the end of combustion the pressure begins to decrease.

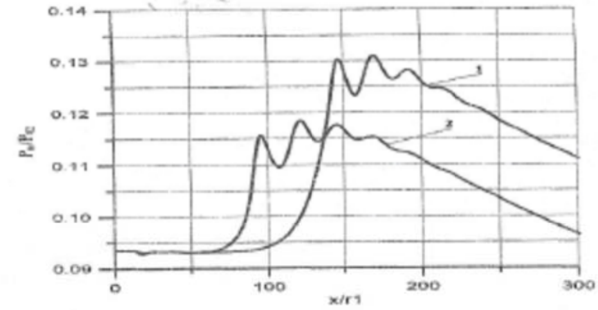

Fig. 3 – Change of wall pressure of Chamber combustion: 1-T_{02}=1920K; 2-T_{02}=2500K

At high temperature combustion is "quiet", because of insufficient mixture, the growth of pressure because of heat input is weak (Fig. 3, curve 2). According to the comparison of calculation data, the growth of pressure depends on intensively of chemical reactions. As seen in Fig. 3, intensive combustion increases the pressure to 11,4% in comparison with diffusion regime.

CONCLUSION

From the results of the research it is possible to draw the following conclusions:

1. Calculation data describe effect of the temperature of supersonic flow on diffusion combustion of non-mixed gases at overexposed regime of outflow of circular hydrogen jet in cylindrical chamber of combustion.
2. Calculations determined borders of stable combustion of hydrogen in coaxial supersonic flow, flame structure in dependence on operating conditions. It was showed that overexpansed regime of outflow is the most favorable for mixing and combustion of non-mixed gases.
3. It was found that at the value of the temperature of flow stagnation T_{02}< 2000K the determining factor of the process is velocity of chemical reactions. Increase of stagnation temperature T_{02}>2500K produces inert behavior of diffusion combustion od non-mixed gases.
4. The growth of pressure depends on intensively of chemical reactions. According to the calculations intensive combustion increases the pressure to 11,4% in comparison with diffusion regime.

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THE METHODOLOGY OF BUILDING THE HEAT AND MASS TRANSFER EQUATIONS WITH ACCOUNT OF NON-LOCAL PHENOMENA IN CONTINUOUS MEDIUM

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Abstract: The paper deals with mathematical models describing heat and mass transfer and aggregation processes with the help of relaxation transfer kernels approach, which opens up fresh opportunities for detailed study of influence of relaxation times hierarchy on the intensity of high rate and nano-scale technological processes. The approach of relaxation transfer kernels can be tested for modification of the Becker-Döring aggregation-fragmentation equation too. It may be interesting also to consider the problem of the gelation behaviour of the system described by new evolution equations.

In our opinion, the relaxation kernels approach may be considered as the unified method for creating engineering models of transfer and aggregation processes. We think, this problem merits closer inspection of investigators.

Keywords: aggregation processes, kinetic equation, multicomponent system, dispersed systems, probability of binary and multiple collisions

INTRODUCTION

Consideration of relaxation times and long-range interaction of structural components of a medium is a great practical and theoretical problem [1–3] that is relevant in cases of high rate or nano-scale technological processes. The operation cycle of these processes is short, and the entire process may go on under the transient regime. In this connection, resources of effective controlling such processes are limited, and it is important to calculate correctly and select the best values of governing parameters. Problems of modeling both high rate and nano-scale processes are in touch with construction of equations with retarded or divergent arguments that reflects the actual mechanism of transfer phenomena in the medium modeled as a system of interacting oscillators with a set of partial frequencies and interaction potentials [2, 3].

At the same time, though realization of that investigation program is very tempting, it's unlikely to promise near creation of the reliable engineering methodology for calculating heat and mass transfer processes. The alternative approach to the problem is the methodology of relaxation transfer kernels, which can be calculated from model evolution equations [3]. In a few articles before we elaborated upon this approach to modeling heat and mass transfer in high rate processes [3-8].

In this article we summarize briefly our results in the area of description of time nonlocality applied to heat and mass transfer and try to develop this approach for describing time nonlocality in aggregation processes. We concentrate our attention upon a problem of equations structure, touching on the problem of analytical solutions of government equations in the lesser degree.

MASS AND HEAT TRANSFER EQUATIONS

Relaxation transfer kernels are the kernels of integral transformations that, in the statistical theory of dissipation processes, relate fluxes with thermodynamic forces [1]. The general structure of these relations for components fluxes in a multicomponent system according this methodology is like that [6]

$$J_i(R,t) = J_i(R,t_0) + \sum_{k=1}^{n} \iint dt_1 dR' N_{ik}(R,R',t,t_1) F_k(R',t). \qquad (1)$$