ELECTRICAL AND MAGNETIC PHENOMENA UPON THE SHS PROCESSES

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An SHS process is one of the most interesting objects in the study of the influence of the electrical and magnetic fields on the combustion processes and property of the products [1-3].

The phenomena arising in the SHS condensed systems in the presence and absence of an electric and magnetic fields are described below.

Experimental

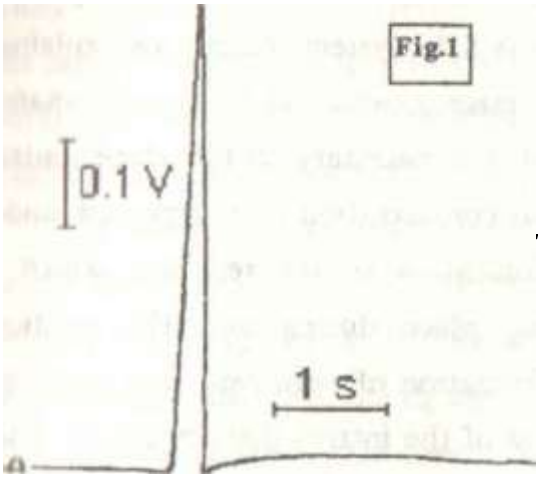
As system studied some liquid-phase (Ni-Al; Ta-Si; Ti-C; Ti-N; BaO_2-Cr_2O_3; Li_2O_2-Cu, Fe) and solid-phase (Ta-C, Nb-B, Mo-B) ones were choose. The powders of metals (the purity no less than 99%) and non-metals (the purity no less than 96%) with the particle size less than 50 microns were used in the experiments. The green mixtures of the initial components taken in the appropriate stoichiometric ratios were prepared by mechanical mixing in a ball mill up to their complete homogenization. The resultant green mixture was used for preparation of the sample of a filling density or slight compacted samples.

By electrical measurements the samples were put into a quartz vessel located in the quartz flow reactor. The metal electrodes were displaced in the samples along the vessel axis. V-shaped chromel/alumel or tungsten/rhenium thermocouples were also placed inside the sample at the distance of 20 mm for taking the combustion temperature and burning velocity readings. If necessary, the reacting (nitrogen, oxygen) or inert (argon) gases were pressure- fed into the reactor to remove impurity gases contained in the green charge. After the beginning of the reacting or inert gas, the reaction was initiated. The difference in the values of the potential on electrodes and the data of the thermocouples were registered by the time-recorders. The electric field was imposed on the system via two copper plates displaced outside the reaction zone and fed by a regular bipolar *dc*-voltage source (2.5 kV). By magnetic field actions the samples were displaced within of a electromagnet coil without a core or between the poles of permanent magnet (3 kOe).

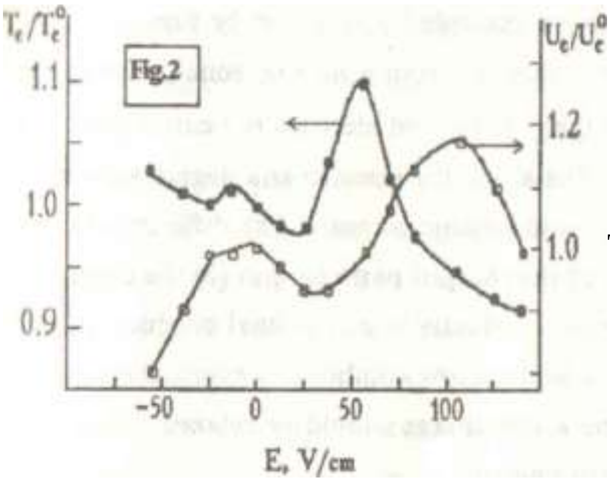
Results and Discussion

Electrical Effects

At the stable combustion wave propagation, the signal of the difference in the electrode potentials was found to arise in all systems studied in the absence of measurement current or an electric field applied. The visual control showed the appearance of the signal only after the front had touched the second registering electrode. Further, the intensity and the character of the signal could change with time dependent on the process parameters, the component compositions and the type of interaction in each particular system.



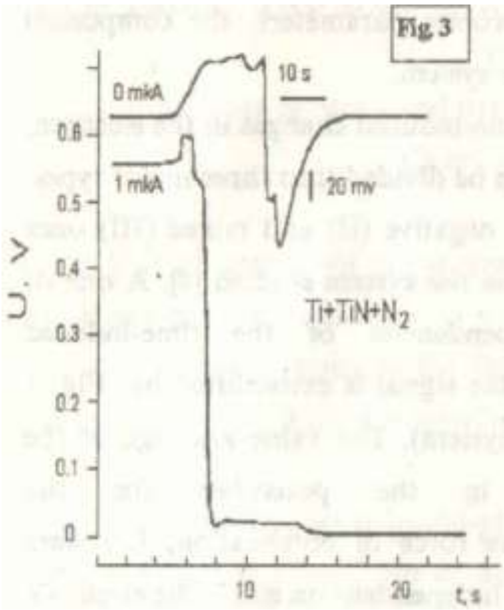
The time-induced changes in the electrical response can be divided into three major types: positive (I), negative (II) and mixed (III) ones depending on the system studied [4]. A one of typical dependencies of the time-induced changes in the signal is exemplified by Fig. 1 (the Ni-Al system). The value and sign of the difference in the potentials (or the electromotive force of combustion, E_c) were found to be independent on either the electrode parameters or on the distance between them provided their diameters were small and they were inactive towards the burning components of the charge.



The study of the electric field effect for the case of collinearity of the vectors of the combustion velocity and the field strength was carried out in a number of typical SHS systems characterized by various types of interaction and the electromotive force of combustion. In all cases, the combustion temperature and velocity were found to depend on the value of the electric field strength E, which was determined by the E_c value in the system

studied. As an example the field dependencies of the combustion temperature T_c and burning velocity U_c normalized to the corresponding values at the zero field are shown in Fig. 2 for the system with the type I electrical response (Ni-Al). Non-monotonous dependencies of the combustion parameters with the maxima in the positive region of the E values were characteristic of the system.

An SHS process in the heterogeneous system is known to proceed in the regime of the combustion zone propagation. Since the medium structure is characterized by the degree of heterogeneity, the steady-state of the combustion front propagation is determined by the processes of reaction diffusion in the



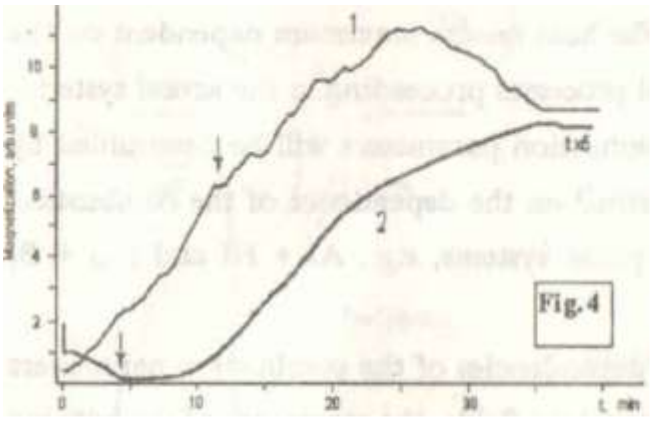
region of the mobile boundaries and heat transfer under the effect to the chemical heat sources available at those boundaries. However, a non-thermal effect of the electric field on the combustion process parameters in the SHS systems cannot be explained within these macrokinetic and thermodynamic approaches and it is necessary to introduce ionized particles [5] into consideration of the process under study. Some ionization of the reagents, which is probably taking place during an SHS reaction, promotes the formation of negatively and positively charged particles of the intermediate products. They may have various geometry, composition and diffusion ability. Due to the difference in the diffusion coefficients, the particles get separated and a certain difference in the potentials may arise at some distance in the zone of the intensive chemical reaction. As a result, the further run of the diffusion processes of the charged particles is inhibited and a double electrical layer (stationary on the distance and the strength) establishes due to the selective adsorption of the ions, which add to the crystal lattice of the solid phase. The difference in the potentials characterizing the layer may be named the electromotive force of combustion. Since the combustion products in all systems under study possess noticeable conductivity (see for example fig.3), it can be supposed that the electromotive force of combustion registered takes off from a narrow zone (between the reacting product containing the active ions and the post-reacted electrically neutral product) moving along with the combustion wave front. Therefore, the positive and negative parts of E_c would respectively correspond to the cationic and anionic currents. The difference in the signal shapes is probably caused by (1) the type of the charged particles and (2) the degree of their activity, which is determined by the electrical conductivity of the final product. In the systems of high conductivity of the final product and narrow combustion zones, the part of the time dependence of E_c that compensates the active charge should be relaxed fast in the final product and a single polarity signal will be registered.

Dependent on the direction of the field applied some extending or compressing of the double electrical layer takes place upon imposition of the electric field on the SHS system, *i.e.* the boundaries of the layer are moved by the field through the specific zones of combustion thus affecting the burning velocity and temperature. First, it can be supposed that the double layer may be located both ahead of and behind the heat release maximum dependent on the character of the macrokinetic and electrochemical processes proceeding in the actual systems. Then the influence of the electric field on the combustion parameters will be determined by the salient features of the SHS system. It was verified on the dependence of the combustion parameters on the field in the solid- and liquid-phase systems, *e.g.*, Al + Ni and Mo + B, i characterized by the close values of E_c [6].

In the Al + Ni system, in particularly, the dependencies of the combustion parameters on the electric field strength have their maxima at various fields, the maximum of the burning velocity being observed in the higher field (Fig. 2). Such a behavior is probably determined by the single polarity of the E_c signal, *i.e.* at the counterion part of the double electrical layer located close to the highly conducting layer of the final product. Consequently, the effect produced by the field applied should be single-polar and the maximum value of the burning velocity is observed, when the thickness of the field-modified double layer becomes equal to the width of the zone of the efficient ionization of combustion. In this case, it can be explained by the increase in the local density of the active ions. Division of the E_c value on that of E at the maximum of the burning velocity gives the width of the zone of the efficient Ionization of combustion no higher than 0.05 mm. This value is rather close to the scale of the system heterogeneity, therefore it is evident that ionization can be efficient for the intermediate products only. At the same time, the higher field value for the maximum of U_c as compared to that of T_c indicates that the double electrical layer is located inside the narrow peak of the heat release maximum.

Magnetic Effects

Magnetic phenomena during and upon the combustion synthesis of alkaline metal ferrite and structural and magnetic properties of the ferrite were studied. A dc magnetic field was applied to a sample during combustion. Combustion of powdered Li_2O_2, Fe_2O_3 and Fe mixtures was carried out in open air. Burning velocities ranged between 0.1 and 1.2 mm/s, depending on charge composition. The combustion temperature did not exceed 1220 K. Final products exhibited anisotropy in residual magnetization whose value depended on the orientation of applied magnetic field with respect to the direction of wave propagation. Longitudinal magnetic field was found to result in an increase in the saturation magnetization of final products due to agglomeration of magnetic particles. For Li-Fe-O system, a successful attempt was made to trace the kinetics of intermediate products by in situ magnetization



measurements when the electromagnetic coil used as received one of a magnetometer. In zero magnetic field, the magnetization vs time dependencies, for lithium ferrate $LiFe_2O_4$

(1) and ferrite $LiFe_5O_8$ (2) was found to be different because, for ferrite, the combustion temperature (840 K) was below the Curie point of both the raw material and final product.

Fig.4. shows that magnetization of the burning samples, generally, increased with time. For system 1, the magnetization pass trough a minimum and for system 2 trough a maximum. In both the cases, main changes in the magnetization were observed largely behind the combustion wave front (the arrows point on the end point of the combustion propagation), during sample cooling. It is assumed that the observed increase in the magnetization is caused by structure transformation post-processes because (i) the content of final ferrite increase in the course of cooling and (ii) the magnetic properties are temperature-dependent.

Conclusion

Electrical and magnetic phenomena accompanied of combustion wave front propagating in the SHS systems are discovered. They are attributed to electrochemical and magnetization processes in the system studied. The effect of external electric and magnetic fields on the combustion process is described.

Nomenclature

E_c - electromotive force of combustion, T_c - combustion temperature, U_c - burning velocity, E- electric field, U - voltage across the system, t - time. Subscripts: 0 - zero field.

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