TROUBLESHOOTING AND MANAGEMENT OF ACTIVATION ENERGY IN ENERGY EFFICIENT ELECTRIC TECHNOLOGIES OF SELF PROPAGATING HIGH TEMPERATURE SYNTHESIS

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Abstract- The paper interests to the process of self-propagating of high-temperature synthesis [1] (SHS) possessing significant technological potential which continues to grow. The majority of recent scientific works (XIII symposium on burn and explosion - Chernogolovka 2005, «Topical issues of radio physics - TSU 2006, etc.) it is dedicated to the technological burn, for obtaining finished products with the required properties. These are highly rigid tool and abrasive materials, wear-resistant and hardening coatings, electroconducting and ferromagnetic ceramic materials, nanostructures. They are actively used in different areas of national economy.

Keywords: Self-Propagating High-Temperature Synthesis, Active Management, Troubleshooting, Electric Heating, Activation Energy.

I. INTRODUCTION

Being the major technological cycle in many production processes, SHS imposes severe requirements to the developed control means. This determines the creation of more complex troubleshooting systems that increase precision of measuring of certain parameters and decrease time of obtained data processing. Chemical interactions of SHS that are characterized by stoichiometry, degree of conversion, kinetic constant, thermal effect, as well as activation energy are the basis for obtaining of intermetallic compounds and majority of synthesized composite materials. Therefore development of devices and technical tools for management of physical and physical-chemical parameters of high-speed interactions and energy efficient technologies is an important technological task. External influence taking part in technical management of SHS process exposes additional challenges in the solution of multi-factor task that is introduced by activation energy troubleshooting.

II. ACTIVATION ENERGY TROUBLESHOOTING

The aim of this work is to develop theoretical principles for troubleshooting and active management of activation energy in SHS processes, implementation of which is not only topical in industrial production but in revitalizing of equipment and tools of industrial agriculture as well.

There is a way [2] of determination of activation energy in the mode of thermal explosion (V.B. Ulybin and others), when electric current used for heating of the environment up to ignition is passed through the interacting components of such electro conducting environment. After finding out of thermal induction time

$$t_i = c \rho \, (T^* - T_o) \, / W \tag{1}$$

where t_i is thermal induction time, c is thermal conductivity of component mixture of condensed thermal conducting environment, ρ is density of the mixture, T^* is characteristic temperature of component mixture, at which the heat generation power due to the chemical interaction gets equal to the power of additional heat generation source, T_o is the starting temperature of component mixture, W is the power of additional heat generation source, dependence diagram can be drawn up in coordinates

$$\ln(W) - 1/T^* \tag{2}$$

Activation energy (E_a) is judged by the angle of tangent at the specified point of the diagram. This method does not make it possible to determine E_a in the combustion wave of frontal SHS. The method [3] offered by Yu.S. Naiborodenko and V.I. Itin determines dependence between the propagation velocity of combustion wave and maximum temperature in the front. After drawing up of the diagram in coordinates

$$\ln(V/T) - 1/T \tag{3}$$

Activation energy is determined, where V is combustion wave propagation velocity, T is maximum temperature in the front. The drawback of this method is its labor intensity and low precision rate since maximum temperature in the combustion wave is determined with the help of floating inert marks, while the dependence $\ln(V/T) - 1/T$ is built up based on several experimental points taken from testing with different initial temperatures (conditions). Thus, identification of activation energy via single experiment is impossible in real time.

In our case if we take a look at the simplified model of frontal SHS [4] assuming that the width of combustion front is equal to the width of heating-up zone $\delta_c = \delta_p$, and rejected heat is negligibly small, then we get total amount of conducted heat from interaction zone for the finite increment of time Δt over the final area F

$$Q = q\,\Delta t\,F = \lambda\,\Delta t\,F\,(T_{max} - T^*)\,/\,\delta_p \qquad (4)$$

where T_{max} is maximum temperature of interaction at the moment of time t, T^* is characteristic temperature of batch mixture at the starting point of reaction $(t + \Delta t)$, λ is thermal conductivity coefficient, F is thermal conducting area in the combustion front, δ_p is thickness of interaction and heating-up zone. Change of internal energy in the heating-up zone up to the moment $(t + \Delta t)$, i.e. up to the reaction start temperature

$$U = c\,\rho\,V\,(T^* - T_{ot}) \qquad (5)$$

where T_{ot} is the initial temperature of batch mixture in the heating-up zone at the moment of time t, c is specific heat capacity, ρ is density of substance (batch mixture), V is volume of heating-up zone. Taking into account tolerations the thermal balance can be defined as [5]

$$U = Q \qquad (6)$$

while taking into account electric heating with the capacity of W we get

$$U = W\,\Delta t + Q \qquad (7)$$

Taking (7) in formula (4) and (5) we get

$$c\,\rho\,V\,(T^* - T_{ot}) = W\,\Delta t + \lambda\,\Delta t\,F\,(T_{max} - T^*)\,/\,\delta_p \qquad (8)$$

Thermal induction time from two-component energy influence will be

$$\Delta t = c\,\rho\,V\,(T^* - T_{ot})\,/\,W + \lambda\,F\,(T_{max} - T^*)\,/\,\delta_p \qquad (9)$$

Analyzing the equation (9) taking into account that

$$T_{ot} = T_o + W\,t\,/\,c\,\rho\,V \qquad (10)$$

The initial temperature of reaction will grow with the increase of process time, where T_o is initial temperature of the process at the moment of time $t = 0$, and thermal induction time decreases, and therefore combustion front time increases and reaches its maximum value by the end of the process. This has been verified experimentally. Figure 1 shows the dependence V_ϕ - T_{ot} of combustion front propagation velocity from the initial temperature of reaction [6]. At the electric heating up a single experiment is performed with the identification of the same parameters. Experiments and assessment of experimental data has shown that the combustion front propagation through the thermal conducting mixture of powders, for example Ni-Al, is possible along with the simultaneous heating by the electric current of the mixture itself. Heat generated at the places of electric contacts of particles evenly heats up the entire mixture during the reaction and increases front velocity.

III. TECHNICAL IMPLEMENTATION OF ACTIVATION ENERGY MANAGEMENT

Technical implementation of the aforementioned theoretical principles is comprised of simultaneous measuring of the stated parameters and processing of obtained results in real time. To identify activation energy of the components of condensed electro conductive environment in the combustion wave with changing initial temperature [7], it is necessary to draw up dependence diagram in coordinates $\ln(V_\phi/T)$ - $1/T$ of the single experiment, E_a is judged by the angle of tangent at the specified point of the diagram Figure 2, Area I corresponds to 76 kJ/mole, while area II corresponds to 140 kJ/mole.
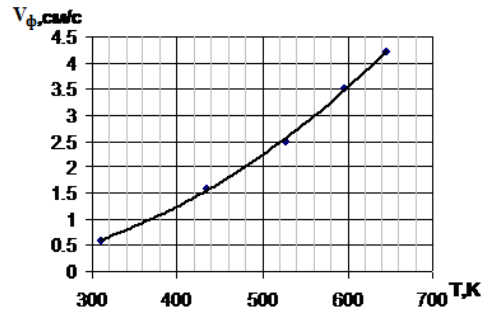

Figure 1. Experimental dependence of combustion front propagation velocity from the initial temperature
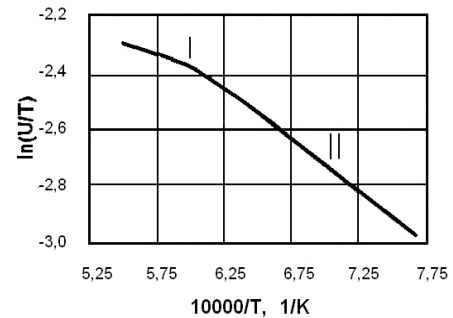

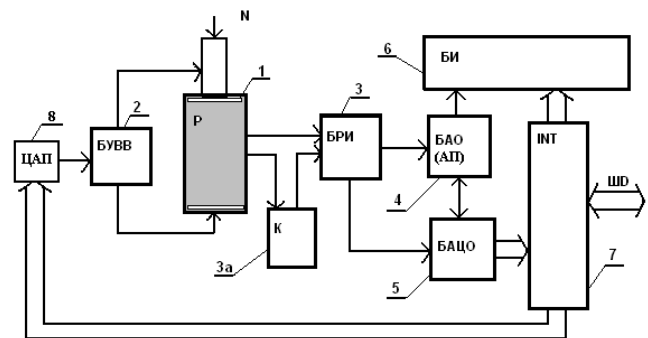Figure 2. Diagram in coordinates $\ln(V_\phi/T)$ - $1/T$

Figure 3. Structural diagram of SHS troubleshooting and management complex

For that reason the SHS troubleshooting and management complex was designed (Figure 3) that includes eight devices operating simultaneously: 1 – SHS reactor, 2 – external influence unit, 3 – detector, 4 – analog processing unit (analog calculations), 5 – digital processing unit, 6 – indication device, 7 – interface and 8 – digital-to-analog converter.
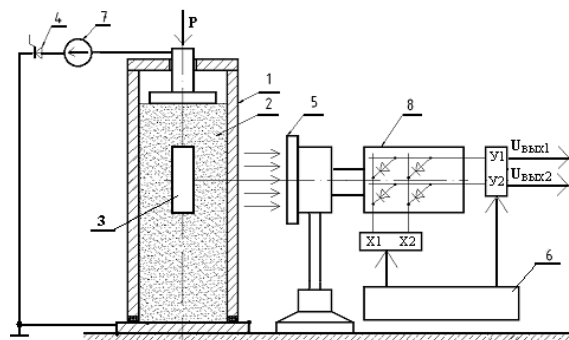

Figure 4. Detection and measuring diagram

After the initialization of the reaction the detection of temperature and its dynamics is performed by primary converter (PC - ПП) based on photodetector array or differential photo diode 8 [8] located in focal plate of optical system 5, Figure 4. External influence is given through the controlled valve 4 by the electromotive source 7 and pressure force P.

Via the query scheme (6) the signals go to the analog-to-digital converter device (ADC) and comparator units with reference voltage that corresponds to the temperature T^* of reaction starting point (Figure 5). Time shift of signals Y_1 and Y_2 determines combustion front velocity V_ϕ. At the moments of appearance the characteristic temperature T^* appears on the outputs of comparator units CA1 and CA2 (Figure 5). Logical «1» forms that assign operation mode to the RS-trigger. After the time-voltage conversion we get signal that is proportionate to the combustion front velocity V_ϕ.
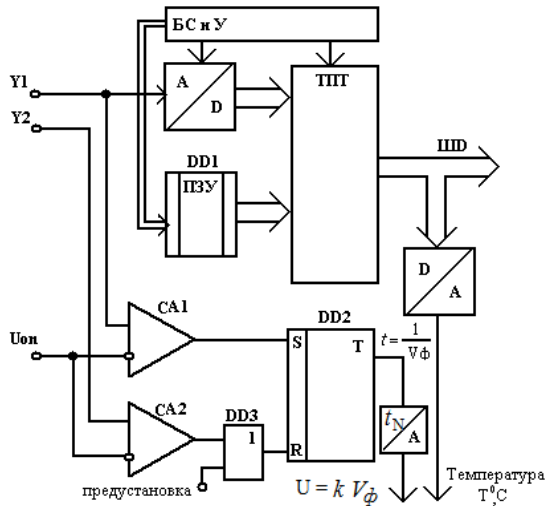

Figure 5. Structural diagram of analog-to-digital converter unit - (ADCU – БАЦО)

Digital signal on the output of ADC that corresponds to the value of the temperature of brightness-temperature pyrometer is compared to the temperature equivalent from read-only memory (ROM - ПЗУ) and is converted by the tabular temperature converter (TTC - ТПТ). Analog signals corresponding to the combustion front velocity and temperature are transmitted to the analog processor (AP - АП) that identifies activation energy (Figure 6).

The design of AP is based on the fast operation amplifiers (OA - ОУ) DA. In order to decrease inaccuracies the transfer constant is taken so that it is approximately equal to 10^6. Determination of activation energy is performed under the analog model

$$E_a = -2R\{[\ln(V_\phi \, / \, T)] \, / \, (1 \, / \, T)\} \tag{11}$$

where R is absolute gas constant, reduced to several math operations over the resulting dynamic parameters and one constant. The first OA - DA1 performs division – these are the signals that are proportionate to the rate between combustion front velocity and maximum temperature
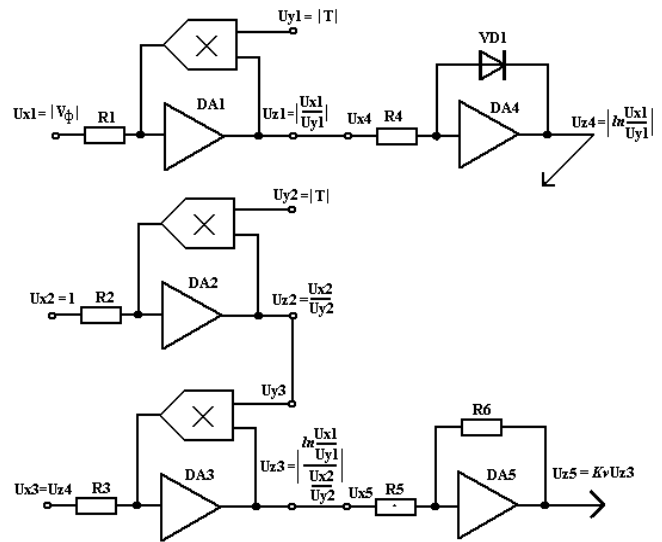
$$U_{z1} = U_{x1} \, / \, U_{y1} = V_\phi \, / \, T \tag{12}$$

Figure 6. Diagram of analog processor

Logorithmation of output signal $U_{z1} = U_{x4}$

$$U_{z4} = \ln(U_{x4}) = \ln(V_\phi \, / \, T) \tag{14}$$

is performed on the second OA - DA4. Operation amplifier DA2 performs division of one by T

$$U_{z2} = U_{x2} \, / \, U_{y2} = 1/T \tag{15}$$

and OA - DA3 performs the function $U_{z3} = U_{x3} \, / \, U_{y3}$, where $U_{y3} = U_{z2} = 1/T$, a $U_{x3} = U_{z4} = \ln(V_\phi \, / \, T)$ or

$$U_{z3} = [\ln(V_\phi \, / \, T)] \, / \, (1/T) \tag{16}$$

Multiplication by the coefficient of proportionality - $2R = K_v = R_2 \, / \, R_1$ is performed by OA - DA5, at the output of which analog signal is formed

$$U_{z5} = K_v \, U_{x5} = K_v \, U_{z3} \, [n\ln]$$

$$E_a = -2K\{[\ln(V_\phi \, / \, T)] \, / \, (1 \, / \, T)\} \tag{17}$$

that is proportionate to the activation energy of component interaction of condensed electro conductive environment in the combustion wave of frontal SHS. The input of E_a value after the ADC into the electronic processing machine is performed via interface.

IV. CONCLUSIONS

The peculiarity of the aforementioned technique is in the fact that the activation energy is identified in the course of synthesis process, which is impossible when using other methods.

External influences as well as initial conditions on the SHS reaction are determined from a single experiment in real time, which not only allows the decrease of experimental costs, but makes it possible to actively manage reaction process as well.

The offered models make it possible to create new energy efficient electric technologies with the active management of SHS and can be implemented anywhere from industrial production to revitalization of industrial agriculture equipment and tools.

Implementation area of this method can spread to similar tasks as well as to creation of simulator models of SHS.

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BIOGRAPHY

Vladimir M. Korotkikh was born on the August 15, 1951. He graduated from Altai State Technical Institute, Barnaul, Russia in 1974. Currently he works as a professor in "General Electric Engineering" of the Polzunov Altai State Technical University. His scientific interests are energy-saving technologies on the basis of self-propagating high-temperature synthesis.