# On the Anniversary of the Phenomenon of "Solid Flame" about Some Features of Modern Practice of the Theoretical Description of Combustion Processes

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***Author's contribution***

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## ABSTRACT

This paper is devoted to a review of the widespread practice of the combustion processes description using the so-called classical combustion theory equations without proper clarification of the real kinetics mechanisms of physical processes under consideration. The «vitality» of this type theoretical description is related to the mathematical properties of the functions used. Below some various examples and historical facts, illustrating the idea, are presented, in particular, connected with emergence and development of the "solid flame" science or SHS (Self propagating High temperature Synthesis), being partially a result of a large policy, associated with the collapse of the USSR.

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# 1. HISTORICAL INTRODUCTION

## 1.1 The Phlogiston

The combustion processes (in general sense) played a major and specific role in the history of civilization. In ancient Greece, Heraclitus taught that everything in the world arises from constantly changing fire, and in ancient Chinese natural philosophy, fire is one of the five fundamental elements of the universe. The role of fire in the development of methods of transformation of matter (from cooking to metallurgy and the production of ceramics) is enormous. And it is no coincidence that one of the first theories that can be considered scientific from the point of view of modern man was dedicated to burning. This is the so-called phlogiston theory (from the Greek φλογιστοζ - combustible) associated with the names of German chemists Johann Joachim Becher and Georg Ernst Stahl. Phlogiston is a hypothetical fluid, according to the authors of the theory, contained in all combustible bodies and possessing a negative mass. According to this hypothesis, combustion is represented as an expansion with the release of phlogiston, which is scattered in the air, forming a visible fire. Despite the absurdity of such views from the point of view of modern science, the phlogiston theory simply and adequately described the experimental facts, was internally consistent, creative, etc. With its help many correct predictions were made and practical results were obtained. The theory was owned by the minds of scientists for more than a century, and its development played a great role in the evolution of science in general and in the creation of a special science of thermodynamics that laid the foundations of all modern science and theoretical physics, in particular (from the Boltzmann H-theorem in statistical physics to the Gibbs potential in chemistry). As an illustration, we can cite the case of the famous chemist Antoine Laurent, whose name is associated with the "oxygen" theory of combustion. Although Lavoisier himself used mainly the theory of phlogiston, he substantiated the successful method of bleaching sugar with activated charcoal on the grounds that the yellowish shade of sugar crystals is given by the phlogiston, which can be removed by making it switch to coal. This successful decision brought the scientist a lot of money (for the sake of justice, he and before that was one of the richest people in France). Then Lavoisier began to participate in the redemption of taxes and this led him to the guillotine of the French Revolution.

The mention of the phlogiston theory is given in view of certain analogies with the current situation that has arisen with the modeling of combustion processes. Now, unlike the times of Lavoisier, the level of understanding of the processes occurring during combustion is much higher. However, I will try to demonstrate, that the so-called Arrhenius equation became an analogue of "phlogiston theory" of the 20th century.

## 1.2 The Arrhenius Equation

As a child, watching his father work with columns of numbers, Svante August Arrhenius acquired a unique arithmetic ability and, already becoming a scientist, enjoyed the fact that he had to look briefly at the experimental data to suggest a formula of regularity. In 1889, he published an article "On the rate of inversion of cane sugar under the action of acids," which is associated with the introduction to physics and chemistry of the famous equation. This equation was not inferred, but suggested, selected from several variants to describe the speed of a specific chemical reaction: the decomposition of cane sugar under the action of acid. In the article of Arrhenius 7 empirical equations from the works of different authors were cited, among which at number 5 there was an equation from the work of Van't Hoff and Schwab 1984, which is close to the modern Arrhenius equation, namely, $\lg k = 5771 / T + 11.695$ for the decomposition of chloroacetic acid In an aqueous solution. The equation was obtained by biggest number of pluses in the correspondence table with the experimental results of other authors, and the corresponding justifications are also given. At that time, there yet were no modern ideas about atoms and molecules, and the kinetic reasoning of scientists of that time is not always easy to understand. Rejecting a possible decrease in internal friction with increasing temperature as the cause of such temperature dependence of k, Arrhenius writes that "there is only one way" - the existence of some hypothetical reaction component, which he called "active cane sugar," the rest of the matter is passive cane sugar. In the other words, he suggested that the concentration of the active sugar is exponentially increasing with the temperature rise. Later, as leaders of the Nobel Committee, both Vant-Goff (1901) and Arrhenius (1903) received their Nobel Prizes, but not for these works. Arrhenius was

awarded for the theory of "electrolytic dissociation," which was also very revolutionary at that time, and in this connection Arrhenius had to survive many attacks from colleges. Nobody believed in the existence of ions in solution, and Arrhenius himself said that this is only a "convenient hypothesis," explaining the observed facts. Simple calculations using Coulomb's formula can show how huge forces are required for to separate cations and anions. For example, according to the memoirs of the Congress of the British Association, physicist Fitzgerald pestered everyone with one question, where do these forces come from? (They did not know about hydration at that time). Another funny case from the life of Arrhenius: a young man was asked to dispose of the liquid in the laboratory, without warning about its properties. The flask contained mercaptan, a substance with one of the odors most unpleasant to humans, and Arrhenius did not know about it at the time. Arrhenius lightly threw it on the road when he was riding home on a bicycle, and most of the city began to smell like a sewer. The Special Commission, after several weeks of discussion, concluded that mercaptan was formed due to unique meteorological conditions and it is unlikely that this will ever happen again.

At the beginning of the 20th century the profound changes in the atoms and molecules structure understanding took place, and a modest article by Arrhenius on a rather narrow study results "fitting" became a revolutionary milestone in the development of chemistry and other sciences. It made it possible to describe quantitatively the most complicated physicochemical processes. The Arrhenius equation began to be derived both from the point of view of the molecular-kinetic theory and more complex mathematical constructions, for example, inverse Laplace transforms, using various theoretical approaches: thermodynamic, collision theory, transition state theory, stochastic approaches. The modern bibliography on the Arrhenius equation is extensive. It turns out that the "rate constant" used in chemical kinetics is called a constant only by tradition and only formally. In fact, it is a very complex parameter, which includes many physicochemical parameters of the systems under study. This was paid special attention in the 60-70-ies of the last century (especially in connection with the study of plasma-chemical and radiation-chemical processes). In this connection, it is interesting to note that the Chancellor of Germany, Angelina Merkel, was engaged in radiation chemistry, and her doctoral

dissertation was devoted precisely to the "comparison" of the so-called statistical and kinetic reaction rate constants. Many works connected with this equation concern the nonequilibrium of real processes, the presence of several temperatures and generally different constants in one elementary act, the concepts of Arrhenius and non-Arenius kinetics.

However, the "phlogistic" essence of the Arrhenius equation is much simpler: this equation, paraphrasing the name of one famous article by E. Wigner ("The Incomprehensible Efficiency of Mathematics in the Natural Sciences") it is an "inconceivably effective mathematical" object, making possible to close almost any system of macrokinetic equations or formally "simulate" almost any "burning" experiment. In fairness, other functions with a strong temperature dependence (for example, a power law or a polynomial one), can be used as closing functions that describe the chemical interaction in combustion, the main thing is the presence of coefficients that can be varied to "fit" to the experimental data. But the Arrhenius exponent unlike these functions seems to have a physical and chemical meaning and the "fit" turns into "modeling", as if based on the laws of nature.

## 1.3 Semenov

A few words about the origin and development of the macrokinetics of combustion historically. In the late 1920s and early 1930s, Nikolai Semenov published several papers with the opposite content: a chain theory based on tracking the multiplication and death of active radical particles, and the theory of a thermal explosion based on the fact that combustion occurs in the same laws as the breakdown of dielectrics. He dedicated the work on chain reactions to members of the Swedish Nobel Committee, and one of the first Nobel Prize winners chemists Arrhenius and Van Hoff - his "great distance teachers", for which he was persecuted for «idolatry before the West», but was also awarded a corresponding Prize (1956). Another series of works led to the development of the so-called thermal theory of combustion by Zel'dovich, Frank-Kamenetsky, and Todes. The term "thermal" is associated with emphasizing the main mechanism for maintaining, accelerating the physicochemical process - due to the Arrhenius temperature dependence, in contrast to the so-called "chain" mechanism associated with taking into account the real

elementary reactions responsible for the combustion of gases. The fact is that the reactions between the valence-saturated molecules have enormous activation energies in comparison with the reactions involving free atoms and radicals (by tens of kcal / mole more) and the real mechanism of interaction is determined by the fast reactions of the chain carriers and by how they multiply and perish. Meanwhile, the desire to simplify the consideration of the systems of equations for the physical and chemical combustion processes, and sometimes even analytically solve these systems (simplified methods of integrating exponentials, narrow-band methods) led to the use of expressions for the reaction rate with the chemical part of the process the Arrhenius exponents for the zero or first order reactions, ignoring the real dependencies on reagent concentrations, with meaningless activation energies and pre-exponential factors chosen to be satisfactory to the experimental data. This approach now is very widespread under the name of global kinetic mechanism. For example, in [1], an empirical kinetic scheme is used for the single-stage combustion of methane with oxygen. The kinetic parameters are chosen from the experimentally measured flame velocity, and this allowed calculations of two- and three-dimensional flows, including turbulent ones.

## 2. THERMAL THEORY OF COMBUSTION

Returning to history, it must be said that in the 30s and 40s of the last century the works of Zel'dovich, Frank-Kamenetskii and other researchers had created a classical combustion theory, which was a continuation of the Semenov's of the thermal explosion theory, based on the assumption that combustion takes place according to the same laws as the breakdown of dielectrics.

Originally, the theory was developed with reference to the combustion of gases and was based on a joint examination of the system of equations [2]:

$$\frac{d}{dx}\left(\lambda \frac{dT}{dx}\right) - cU\frac{dT}{dx} + Q\Phi(T, a_i) = 0 \qquad (1)$$

$$U\frac{d\eta}{dx} = k_0\varphi(\eta)\exp(-E/RT) \qquad (2)$$

$$x \to -\infty: T=T_0 \; ; \; x\to: T=T_b \qquad (3)$$

(where x is the coordinate, λ is the thermal conductivity, T is the temperature, c is the specific heat, U is the combustion rate, Q is the thermal effect of the chemical reaction, Φ is the rate of the chemical reaction, η is the reaction depth, $k_0$ is the rate constant of the chemical reaction, Φ (T, a) is the kinetic exponential function, E is the activation energy, R is the gas constant, $T_0$ is the initial temperature, and $T_b$ is the combustion temperature).

Heat and mass transfer consists in heat conduction and diffusion, the fields of which are similar, and chemical kinetics in the exponential dependence of the reaction rate on temperature. For the combustion of gases according to the scheme of the simplest first-order reaction (the burning rate is proportional to the concentration) using various assumptions, as well as the original approximate calculation methods, an analytical solution was obtained: the burning propagation velocity turns out to be in the "Arrhenius" dependence on the combustion temperature.

$$U \sim \exp(-E/2RT) \qquad (4)$$

where E is the activation energy; R is the gas constant; T is the temperature.

The results obtained for the simplest reactions in the gaseous medium have been used for to study of many various systems (condensed, homogeneous, heterogeneous, explosive substances, etc) burning. It is necessary to note the real importance of many results obtained with the help of these approaches: a correct qualitative understanding of the various moments of the propagation of combustion waves, the theory of limits, stability of combustion regimes, etc.

## 3. CRITICISM OF THERMAL THEORY

But the main property of the equations under consideration and their ability to describe the combustion waves quite accurately is due to the presence of power and exponential dependences in the formulas and the ability to vary the values of the coefficients.

As already mentioned, the mathematical essence of the problem is quite trivial. Models based on the equations of conservation of energy, matter, components and the Arrhenius conjecture can be written in the following form:

$$\Sigma\, F_{phys} = \Sigma\, F_{chem}(\exp(-E/2RT)) \qquad (5)$$

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where on the right side the functions responsible for the chemical processes and containing the Arrhenius exponential for the rate of chemical reactions are summed up, and in the left – the functions responsible for the physical processes: thermal conductivity, diffusion, convection, radiation, etc. It turns out that the mathematical properties of the functions used make it possible to describe practically any experimental data in the field under consideration. Indeed, if the right and left parts of such expression are logarithmized, this operation, without changing the essence of the relationship, so "smoothes out" the features of functions that did not initially contain an exponential, which they can often be neglected. In other words, the exponent is so "strong" function for adjusting the results, that using it in such equations, you can "no bother" how accurately it was possible to describe the actual physical processes, so, paraphrasing a well-known expression, we can say that the exponent "throws out with the bathwater the baby "- a reality.

It should be said that Semyonov himself tried not to participate in the development of the thermal theory, and was included only when it was possible to show the chain nature of the chemical part of the macrokinetic process. However, Semenov was seriously criticized by the less educated politicians from science, who were then not only in biology (Lysenko), but practically in all areas of science in Soviet Union. Ironically, these figures from the burning: Akulov, Frost and others tried to seem even more supporters of a chain theory than Semenov himself. When the clouds over the scientist-burners were already heavily condensed and they were threatened with real repression, a "bomb" (nucler) came to the aid, our contribution to the theory of explosion of which consisted of thermal theory, and, of course, ... the Nobel Prize. Uneasy stories of the lives of these people can be learned from various published memoirs. The apotheosis of history with Semenov, in my opinion, is a change in his point of view on the nature of the third limit of hydrogen burning with oxygen. According to one version, presented in Semenov's monograph [3], he suddenly believed Frank-Kamenetsky's calculations that the constants taken from the experiment (the global-kinetic mechanism) describe combustion at high pressures well. Meanwhile, among the scientists retells the story of how exactly the then president of the Academy Alexandrov made Semenov write that hydrogen with oxygen explode at the third limit by the thermal mechanism. In addition,

Alexandrov is credited with defending and deflecting the threat of repression from many scientist-burners.

Continuing on the existing practice of mathematical description of combustion processes: such fitting modeling is usually discernable: important physical processes, the pre-exponent and the activation energy in the laid-down chemical equations are ignored, the various parameters differ in order of magnitude from the meaningful ones: the dimensions of the combustion zone, the characteristic times take unrealistic values. Similar situations, when theoretical models are fundamentally different from what is happening in reality, are very widespread in combustion theory.

## 4. THE EXAMPLE OF "THEORETICAL" WORK

As an illustration, one of the works [4]: titanium is poured into the boat and covered with quartz glass (Fig. 1). Titanium is ignited in air, which passes through a narrow slit. Vibrational combustion is observed. But what is really happening? As the ignition begins, an impurity gas begins to emanate from the titanium, which is there (0.1-0.3% of the mass) due to the peculiarities of its production from the titanium sponge and interferes with the supply of air, the combustion decays and the impurity gas becomes smaller. It flares up again. With powder titanium, you can come up with other variants of the "Chinese" smoker. What do the theorists do: ignore everything that has been said above about impurity gas evolution. A standard system of equations of the type (1-3) is written and the observed oscillations arise due to the properties of the exponentials. Thus, there are quite certain processes, but in the formulas laid down a very different process, but the result seems to be the same.

As already mentioned, the boom of these equations usage is associated with the development of a computer account. For a few decades, a lot of works on this subject have been written, and many are connected with the calculations of military and space technology. It can be said that a whole theoretical branch of science has appeared or even several such sections that solve various problems related to combustion: stationary, nonstationary, one-dimensional, two-dimensional, three-dimensional, with a different number of chemical reactions and various kinetic functions; Instabilities, pulsating regimes, spin, the
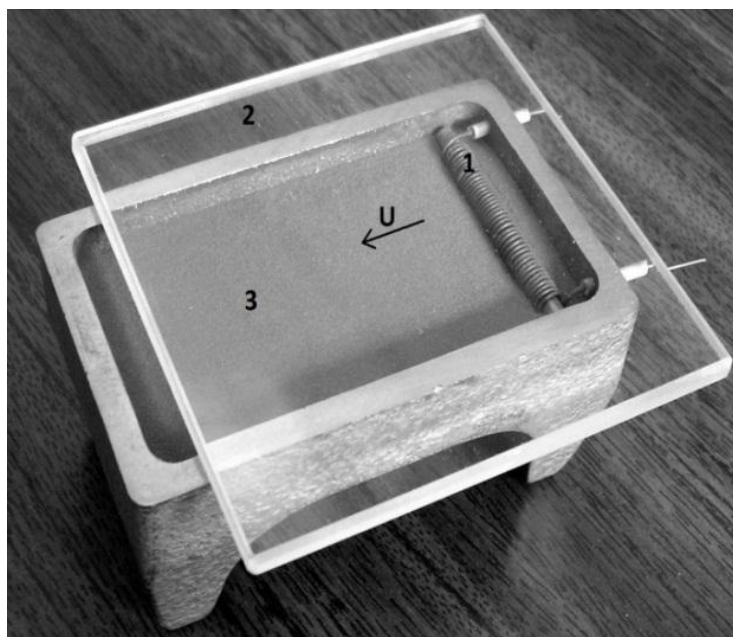
**Fig. 1. 1 - Ignition spiral, 2 - Quartz glass, 3 - Initial powder layer,
U - Front velocity [4]**

development of fingers, etc. In other words, the characteristics of certain hypothetical objects that are far from the physical and chemical processes occurring in reality are studied.

## 5. SELF-PROPAGATING HIGH TEMPERATURE SYNTHESIS (SHS)

### 5.1 History SHS

Another example of the application of the classical theory of combustion is the so-called "solid flame" story. By the way, this year's anniversary, 50 years of SHS, "self-propagating high-temperature synthesis" (still synonymous with "solid flame", "gasless burning", "Russian process"). Quotation from the text of the "discovery": "It is experimentally established that the phenomenon of wave localization of self-locking solid-phase reactions, unknown earlier, consists in the fact that the chemical interaction between solid dispersed components without melting and gasification of reagents and products", etc. About how this formulation arose, writes in detail Academician Merzhanov in his memoirs [5], it was necessary to fulfill the requirements of the patent service agent, who helped to issue the documents. And why 50 years? - the discovery was recorded in hindsight with the priority of 1967. In fact, in all these

processes, something is always melting, gasifying, there are no "auto-braking" reactions, their experimental establishment and other things contained in the text of the discovery. The peak of the development of the subject fell on the 80s, the time of the collapse of the USSR. According to ISMAN-inform, several scientific papers were published per day, work from 47 countries of the world was recorded. In several universities there appeared the chairs of SHS (many of them still exist), were reported on successful introduction to production. Recently, the Institute of the Russian Academy of Sciences ISMAN was named after Academician Merzhanov in honor of the anniversary of the SHS. The best way to understand the phenomenon of SHS is to refer to the memoirs of the participants in the events and their surroundings. For example, the American participant John Kaiser turned out to be a prolific writer and for his part himself published a book [6] in which he told how the government concluded an agreement with him on relevant activities in Eastern Europe, whose aim was to try to use the results of socialist science in the United States, and the arrangement of various "mousetraps" for the USSR. («We helped industry to put Russia and Eastern Europe on the map as places to seek better or cheaper mousetraps, and acted as midwives in the process»).To the exact sciences after the USSR, John Kaiser no longer touched, but switched to

writing texts about Islam and the Islamic threat long before all the current tragic events in Iraq and Africa. Now he grows pigs in France, everything can be read on the Internet. A good support for the emergence of the SHS project in the USSR was the published in 1980 report Joey F. Crider, US Army Foreign Science and Texnology Center Charllottesville, then immediate supervisor John Kaiser. And the idea to write this document belonged to Jimmy McCollie, the head of the Crider. The report spoke about the Americans' anxiety about the fact that the "reds" invented a miracle - "solid flame", "gas-free burning", "Russian process", new technologies and materials. So, funding is allocated, the Institute is being built. This was one of the last investments of the Soviet Union in science before the collapse. Namely, Gorbachev [7] spoke about these "inconceivable technological breakthroughs" in 1985, when he allocated funding for the project. For the past 30 years, several ISMAN laboratories and many scientists around the world, although not without much success, have been engaged in fundamental and applied research of SHS. However, the followers of Merzhanov [8] compare him with Columbus, who was looking for a way to India ("solid flame"), but discovered America ("new technologies").

## 5.2 Theoretical Description of Combustion Processes

### 5.2.1 Classical theory of SHS

So far, the most common description of the "solid flame" with the help of an example of application of the so-called classical theory of combustion [2]. It arose as a consequence of the classical theory of the propagation of combustion, the theorists have a "solid flame" model, when in the combustion front there is no melting and gasification, which greatly simplifies the physical model. Here we note that the presence of was one of the grounds for the appearance of the "solid flame" predicted "at the tip of the pen" by the theorists of combustion. The search for so-called "gas-free burning" started in the postwar years, led to the fact that Merzhanov [9] with the employees announced the discovery of systems obtained from mixtures of certain substances, in the combustion of which there is no melting and gasification or gas evolution and the presence of the liquid phase is so insignificant that they can be neglected in the modeling of the process. Later these studies were formalized as a discovery of the phenomenon of "self-

propagating high-temperature synthesis" (SHS). So, whatever Merzhanov wrote about the need for the discovered discovery formula for patent purity, the text of the "discovery" fully corresponds to this theoretical model. As a scheme of reactants interaction, a reaction diffusion model was adopted. The process of stationary combustion of a model system consisting of ordered layers of reacting components is considered, with mutual contact of the initial components a product is formed, the rate of heat release is determined by the speed of transport of the reagents through the product layer. The conclusions drawn from the consideration of the model layer system are transferred to the case of combustion of real media consisting of particles. On the basis of numerous approximations, it turns out that the propagation of a stationary combustion wave in heterogeneous condensed media is described practically by the same system of equations of chemical kinetics and heat balance as for combustion in homogeneous media and practically the same for the mass combustion rate $U \sim \exp(-E/2RT)$ (E is the activation energy, T is the temperature, R is the gas constant). There is a typical picture, when, frankly speaking, the incorrect results obtained for the simplest reactions in the gaseous medium, based on the so-called classical combustion theory [2], are used for combustion of many systems, condensed, homogeneous, heterogeneous, explosive substances, deserves a separate discussion. Here we note that the presence of [2] was one of the grounds for the appearance of the "solid flame" predicted "at the tip of the pen" by the theorists of combustion. The theory of the solid flame Merzhanov-Khaikin [10] is an illustration of the incident when the model is completely untrue: the determining processes are ignored, the combustion and heating zones in the model are an order of magnitude larger than those observed in the experiment, which in principle forbids continuum mechanics equations usage for the mathematical description of the combustion process, and many other inconsistencies.

### 5.2.2 Microheterogeneous model (CCM) by Rogachev

For the sake of justice, in addition to the classical theory of SHS due to its obvious inadequacy, other models of the description of "solid flame" appeared during this time. For example, this is the so-called microheterogeneous theory proposed by Rogachev and co-authors [11]. This

theory explains the features of the propagation of a "solid" flame observed as a result of the high-speed video recording as a result of inhomogeneities in the reacting medium. The powder mixture is represented as a set of identical reaction cells, each containing a fuel and an oxidizer in the same proportions as the initial mixture, the temperature and other parameters inside the cell are the same, and the process is spread due to heat exchange between the cells - combustion sites. Many experimental results cannot be explained with the help of this model, since it, like the theory of Merzhanov-Khaykin, does not take into account the actual processes of melt flow and gas evolution. For example, from the point of view of this theory, like the classical theory of Merzhanov-Khaikin, such methods of action as blowing a burning sample with an inert gas in different directions, thermovacuum treatment (drying), various minor (~ 1% by mass) gasifying additives (borax, soda , humidity), should not have a significant effect on the combustion of samples. However, it turns out that the speed of the combustion front can vary very much under these effects [12].

### 5.2.2  Convective-conductive  model  (CCM)  by Seplyarsky

Another model for explaining the mechanism of propagation of the combustion front in SHS processes was proposed by Seplyarsky [13,14] and is called convective-conductive model (hereinafter referred to as CCM). This name is due to the fact that in this model it is assumed that the propagation, why do finer samples burn at a faster rate than thick ones. Indeed, in those samples where the impurity gases that are formed in front of the melt piston and thus inhibit the combustion front, the thicker the sample, the more difficult it is for gases to escape through the lateral surface and is slower more strongly. Also, the above-mentioned effects associated with blowing a burning sample and the like were explained more or less satisfactorily. Nevertheless, many things that are assumed in this model are not true. Namely, there is no continuous melt layer, nor that the combustion zone would have an increased resistance to gas blowing: usually the permeability of the products is higher than that of the initial charge, and the resistivity in the combustion zone has some intermediate value. In addition, the concept of capillary forces in the form δ/r also appears to be incorrect. In fact, in the processes of a "solid" flame velocity of the combustion front is a sum of the classical "conductive" velocity, determined

according to the classical theory of SHS and the "convective" component associated with the assumption that there is an impermeable or poorly permeable piston in the combustion zone from the liquid melt that moves under the action of the gas pressure drop before and behind the combustion zone, and also due to the capillary forces δ/r (δ is the surface tension coefficient, r is the pore diameter). For example, along with the influence of the pressure of impurity gases on the motion of the melt, the determining effect is exerted by thermocapillary forces. Estimates show that the change in the coefficient of surface tension in the combustion zone due to temperature changes is of the order of 0.1 n/m. There are other problems with CCM. For example, the scheme of this model and all the basic equations were formulated in [15], to which the author of the CMC does not refer. It studied the combustion of samples from a mixture of titanium and soot under an argon atmosphere under conditions of a pressure drop along the sample. It turned out that as the pressure drop increased from 0 to 30 atm, the burning rate increased in proportion to the pressure and a stop was created that interfered with the gas flow. To explain the results obtained, it was suggested that in the combustion front a melt layer appears that moves under the action of a pressure drop, a scheme and equations completely coinciding with the scheme and equations of the CCM are given. Because the experiment took place in a thick-walled steel tube where the studied composition was injected, there was great doubt that the stopper interfering with the passage of gas was created by the melt, and that the combustion front was flat enough. In addition, no other experimental work, describing such a piston-shaped melt movement, was not later presented and the authors of [15] in the future practically do not refer to the results of this work.

### 5.2.3 Focal model by Brauer

The author proposed a mechanism explaining the observed phenomena of the "solid flame" and the scheme of the process [16,17], according to which the process is determined by the motion of the droplets of the melt that ignite the substance, the behavior of the formed combustion sites determines the character and speed of propagation of the combustion front. The melt moves under the action of thermocapillary forces and forces of gas pressure. The diagram of the propagation of combustion is shown in Fig. 2. There is no continuous melt zone-there are

individual droplets of melt in the burning zone with an average density $\rho_m$ in the cross section of the sample. The scheme is one-dimensional and one-temperature: that is, in each section the melt is at the same temperature T and the surface temperature of the solid particles is also equal to T. The velocity of the melt droplets $V_m$ is determined by the Darcy law temperature and pressure gradients:

$$V_m = -\frac{K(\eta)}{\mu(T)}(A\,grad\,T + grad\,P)$$ , (6)

where K is the permeability coefficient in Darcy's law, $\eta$ is the degree of chemical transformation, $\mu$ is the viscosity depending on the melt temperature, and A is the coefficient.
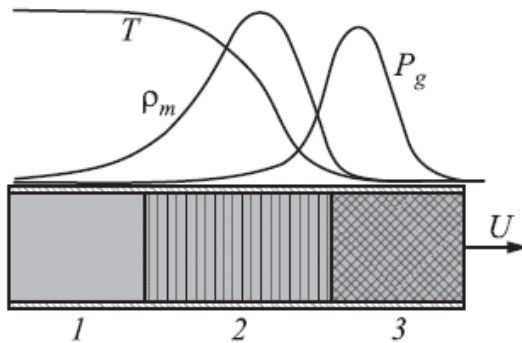


**Fig. 2. Scheme of propagation of "solid flame": 1 - initial mixture; 2 - zone of combustion containing melt drops; $\rho_m$ is the density profile of the melt drops; $P_g$ is the gas and pressure profile [17]**

Thus, according to this model, the fact that systems based on refractory components burn at a relatively high speed, which was one of the reasons to call a "solid" flame the discovery, is related to the properties of the melt formed, drawn from the hot regions into the cold in the direction of the propagation of combustion due to thermocapillary forces. The actual process of melt flow is three-dimensional and depends on a number of parameters: the amount of liquid phase, physical and chemical properties of a solid porous medium and melt, and the topology of the porous medium. Very important are the conditions of ignition and the peculiarities of the development of the foci of combustion. It often happens that the droplets of the melt do not move in the direction of the propagation of combustion, but are practically perpendicular to

this direction. This is due to the fact that as we approach the boundary of the combustion front, the temperature of the liquid heated in the combustion zone decreases and its viscosity increases. For example, the motion of foci of combustion moving practically along the boundary of the combustion front with velocities of 8-20 times higher than the propagation velocity of combustion is observed experimentally. Far from the limits, a large number of similar foci of moving along the combustion front along a spiral (cylindrical patterns) create a practically layer-by-layer propagation of combustion, with high-frequency pulsations, but as the limit approaches, this combustion becomes pulsating, and at the limit, spin, if such a regime in this system is possible.

## 6. THE ATTITUDE OF WORLD SCIENCE TO SHS

Now, a few words about the applied aspects of the usefulness of products obtained by the SHS method and SHS-technologies. Periodically it is reported that some unique and necessary materials have been received, but it usually does not go beyond statements. The problem is that the SHS is a nonequilibrium and poorly repeated process and reports that as a result of SHS the materials and products that the modern science is working on create always cause doubts about their reliability. The world science in the SHS issues moved in the waterway and with an eye to the Soviet and then to the Russian science, many Soviet and Russian scientists left abroad and some manage to get financing there and support the myth of SHS. In fairness, it should be noted from the memoirs of Merzhanov [5] that such famous American experts as Professors Rice, Holt, Munir have reacted to the idea of SHS-technologies with great caution (especially Rice). In his memoirs Merzhanov [5] is described as at a seminar in Monterrey, California, by obtaining insider information about the contents of Rice's critical report, the Russians rebuilt their speeches so as to soften criticism and thereby "defeated" Rice polemically. But the technology of this, of course, did not become better. As already mentioned, other Americans helped the Russian SHS financially and organizationally. Edward Michael organized an international journal "Self-propagating high-temperature synthesis," SHS, which exist to this day. It is characteristic that this magazine did not become formally recognized. And this reflects the attitude of the world science to SHS.

## 7. POLEMIC ISSUES AND CONCLUSION

Why are there few such critical publications with an alternative point of view. Unfortunately, the topic of «solid flame» and the description of various combustion processes with the help of a global-kinetic mechanism and thermal theory among scientists and experts is quite popular and it is quite difficult to publish works criticizing these approaches. It is also difficult to publish articles criticizing the thermal theory of combustion and the global-kinetic mechanisms in general. The author knows several articles with formulas, where the right and left parts have different dimensions or with frankly fabricated results. If this is interesting, author can write a special article about such works. In the meantime, many editor-in-chiefs do not want to publish such materials, they say, give positive results, do not just criticize.

The main question is: how did such problems arisen in the theory of combustion? Is the matter really connected with the above-described properties of mathematical functions used? It turns out that in order to understand how the situation in the field was formed is not enough to read only scientific books and authors' articles. One must also look at the histories of their lives and study the relevant moments in the history of the country and the world, at a time when certain theoretical constructions arose. Thus, the author's hypothesis is that for to understand the situation in modern science it is not enough to study only physics, chemistry, mathematics, etc. The "total history" of any scientific field development must include also an "additive" story, related to the philosophy and sociology. The real political conditions of the scientific researches, their aims and researchers destinies can strongly influence the very science and content of scientific theories and therefore must be taken into account.

## COMPETING INTERESTS

Author has declared that no competing interests exist.

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