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To synthesis of materials by combustion: CCSO and CSS data now available

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This review is a continuation of the previous ones published by one of the authors and is devoted to the combustion community last results related to synthesis of materials and especially to the carbon combustion synthesis of oxides (CCSO) and combustion synthesis of sulfides (CSS). The reason of such an unusual transition from the electric and energetic aspects of the combustion synthesis considered previously to its material properties is explained by the rigid correlation of the product structure and the combustion electric/thermal characteristics. Therefore, even a negligible shift in the combustion front voltage/heat flux leads to strong variations in the combustion product scale. We have just generalized both the thermal and electric aspects in relation to the scale of products obtained.

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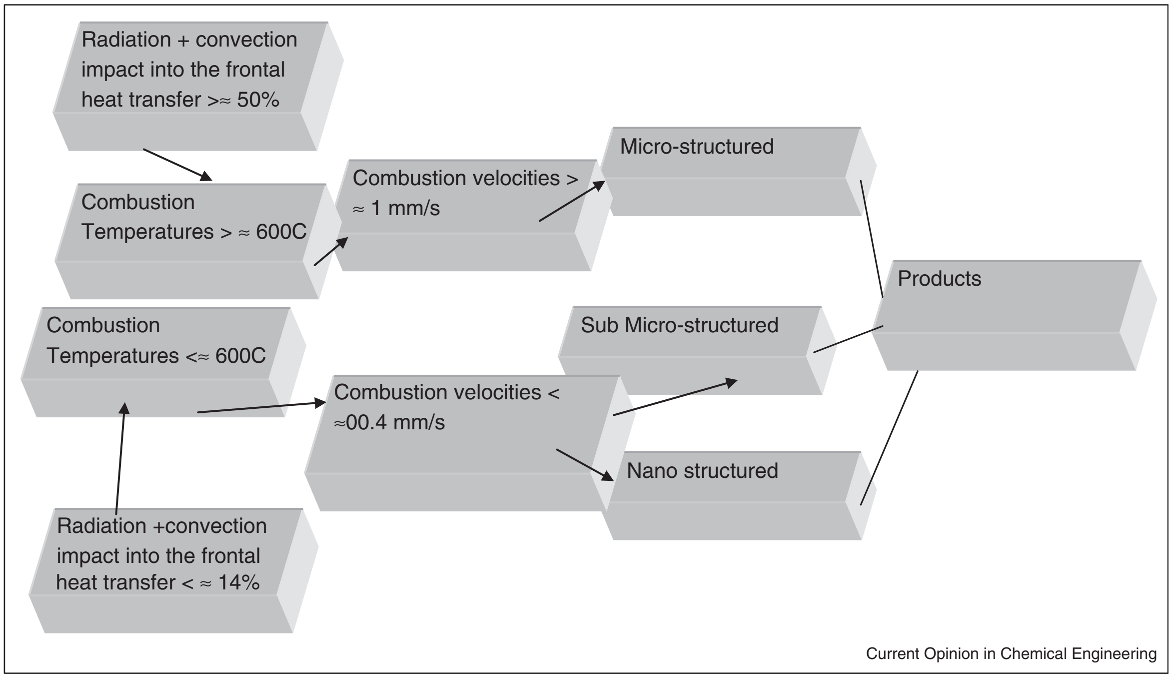
Introduction

We have to notify readers first of all that this review is a natural extension of reviews [1••,2••] published previously. Therefore, some intersections minimized by us carefully can be still possible but those are not so numerous and actually important here. Reviews [1••,2••] were devoted mainly to the effects of the electromagnetic field (EMF) applied externally or generated internally during the combustion synthesis of materials (CSM). The variety of CSM processes have been analyzed from the energetic point of view [1••], and are compared among themselves (ETE, FACS, MICROCOM, etc.). The opportunities to synthesize new materials in the reacting systems of low heat release (such as intermetallic compounds, etc.) under an external EMF or in accompaniment with the radiation combined conductive heat transfer during CSM have been revealed [1••]. Today much more attention of some of the researches is devoted to convection during combustion, both in general [3–7] and, especially, to the convection combined radiation impacting into the heat transfer during CSM [8•,9,10]. The reason is that instead of just the simple and great or predominant thermal action leading to the high temperatures of CSM in the steady state modes of propagation and to dozens or hundreds of microns as the prevailing scales of the product grains, their interests are shifted now to investigation of the more *complex and maybe even precise action of an external EMF and/or convection: when production of the moderate combustion temperatures is still sufficient for a support of the CSM wave at the limits of its propagation but is already insufficient to form the product grains larger than those of about 1 μm in diameter* [11••]. Similar to CCSO [11••] it was shown on the example of the ZnS synthesis [8•] that the excessively high combustion temperatures and the CSM front velocities (developed by the stoichiometric zinc–sulfur mixtures) are provided preferably by the significant impact of radiation combined convection heat transfer into the integral heat flux developed during CSM (>≅48–93%). Vice versa, the non-stoichiometric green charges let us reduce the range of impacts to that comparable with CCSO [11••] (6–14%) at the excess of sulfur initially presented in the green charge. The results of investigations [4–7,8•,10,11••] are summarized in Figure 1. *Another set of researchers* are focused on the kinetic measurements EMF supported occasionally [12•,13–15] or exoemission [16–19], irradiation enhanced reactivity [38•] and the surface carrier states [20,21]. EMF-free comprehensive review of CSM methods have been done in [22,23]. Without EMF, we are deprived of effective means of combustion control. Reviews [2••,16], papers [3,24] and dissertations [2••] were devoted to the experimental; achievements in CSM of the last 5–10 years mainly and to the problems that still remain unsolved by now in this field. For example, emission of the hard high-energy gamma radiation (with the energy up to 150 eV) was detected [44] in some SHS systems but not all the experienced experimentators agreed with these data since there is still no clear understanding of a sensible reason providing such results. In the last few years, a qualitative shift to numerical investigations of convection combined radiation impact into the CS waves heat transfer has happened [8,9,24,25] and it has been shown [26] that the natural convection combined radiation heat transfer accelerates greatly the wave of zinc sulfide synthesis and causes generation of the voltage increased up to 4 times [25]. The calculated effect has been also confirmed experimentally [25].

Figure 1



Characteristic aspects of CSS [8•,9,10] and CCSO [11••] generalized in relation to the products scale

Discussion

One has to understand that there are now a lot methods and techniques which let us obtain new materials. Nevertheless, the most of them are very new and are even not proven. In this relation combustion has the solid theoretical and experimental background [10,23,27–31,32•,33–37,38•,39–41]. This background guarantees certainly knowing of the processes involved and of the possible ways of their management.

Creation or usage of new materials is an actual problem of the humanity throughout of all its history. For example, transition from the stone to bronze ages is characterized by the fact that different people across the globe mastered metallurgy and began use of metal (bronze) tools in their life. Modern age can be characterized not only by a creation of the materials structured on the scale finer than that one previously usual (micron) and, therefore, such materials (structured on a submicron or the nanometer scale) reveal new areas of their application, but also by a skillful combination of a Structurization with new materials which provide a new quality of the material in addition to its advanced quantitative characteristics. Authors [36] have created the carbon-silicon nanocomposite which improved the performance of anode and therefore enhanced greatly the capacity of lithium-ion batteries. Researchers from the laboratory of professor Martirosyan (University of Texas at Brownsville) have also improved the performance of cathode in lithium-ion batteries with the help of the lithium cobaltate nanopowders obtained by CCSO [41]. As the result of their bilateral (anode–cathode) research, all the conditions for uniform high density and non-contracted electric currents inside lithium-ion batteries as well as the market demands are met [36,41] (see also Figure 2). Figure 3 illustrates schematically the main processes incorporated both into carbon combustion synthesis of oxides, CCSO and combustion synthesis of sulfides, CSS. The only difference between them is that CCSO is based on smoldering while CSS uses as a rule filtration combustion, FC, which is faster in general and has the higher combustion temperatures in the stoichiometric green charges (see Table 1). Nevertheless, at the concentration limits of the CSS propagation the CSS front can be even slower than that of CCSO (compare the combustion velocities in Table 1). So-called max phases have been discovered in [26] with no combustion initially applied. These phases (such as Ti_2CdC, Ti_2GeC, Ti_3 SiC_2, etc.) combine the properties previously considered as mutually excluding. They may be refractory and at the same time easily molded at a tool processing. It has been shown now [42] that many of them can be produced by a combination of combustion synthesis (CS) and shift deformations. Recently discovered graphene can be also synthesized in a nanostructured form with the help of combustion [37,40]. First electro-hydrodynamic (EHD) model of an