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Physical Chemistry

Thermal Inhibition of Flame Propagation

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ABSTRACT. **The presented paper is dedicated to the important problem for modern fire-fighting modeling of the inhibition of laminar flame by the particles of inorganic salts. The main goal of the work involved the clearing of the fact: may the effect of flame cooling (thermal inhibition) by mentioned particles contribute significantly in the process of flame propagation suppression. The inhibition of the combustion of simplest hydrocarbon – methane by the particles of sodium chloride of various size was selected as the model process. The velocities of heat release in the flame zone and of heat transfer to the cooling particles from the flame zone were calculated theoretically. The ratio of these velocities was taken as the quantitative measure of the efficiency of cooling action of solid particles. Numerical integration of appropriate functions was carried out by Simpson's rule. The results obtained show that the sufficiently large part of heat energy, released in combustion zone, is transferred to the solid particles and is not consumed for the flame further propagation, hindering the combustion process. Consequently, besides the chemical inhibition, thermal effects must be taken into account in the course of the study of complex process of the extinguishing of combustion reaction.**
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Key words: combustion, thermal inhibition, fire extinguishing powders

In the last few decades the special fire-fighting powders, prepared on the basis of natural mineral resources and inorganic salts, are succesfully used in fire-fighting practice [1-5]. They are characterized by low toxicity, high activity and universal action [6]. Along with it the detailed mechanism is not adequately studied up to the present .

At present it is assumed that the inhibition of flame propagation by the particles of small size may be mainly determined by homogeneous and heterogeneous inhibition of combustion reaction . The main goal of presented paper involves the explanation of the fact: may the effect of flame cooling (thermal inhibition) by mentioned particles contribute significantly in the process of flame propagation suppression.

It is known that the one-dimension stationar model of laminar flame may be expressed by the following manner :

$$\frac{d}{dz}\left(\lambda \frac{dT}{dz}\right) - \rho_0 v_0 \left(C_P \frac{dT}{dz}\right) + \omega_+ - \omega_- = 0 \ . \quad (1)$$

Here z is the coordinate taken along the normal traced to the flame front, λ – coefficient of heat conductivity of the gaseous mixture, T – gas temperature, ρ_0 – the density of initial reaction mixture, v_0 fundamental velocity of flame propagation, C_p – gas heat capacity. ω_+ and ω_- correspond to the velocities (in terms of volume unit) of heat release in the flame zone and of heat transfer to the cooling agent from the flame zone. In our case the solid particles of fire-extinguishing powder present the cooling agent.

The velocity of heat release in the combustion zone may be presented as the product of the velocity of combustion reaction (ω_R) and thermal effect (Q) in terms of one mole of reagent:

$$\omega_+ = \omega_R \cdot Q = -\frac{dc}{dt} \cdot Q = -\frac{dc}{dz} \cdot v_0 \cdot Q . \qquad (2)$$

Here C corresponds to molar concentration of the reagent. According to the principle of “the analogy of concentration and temperature fields” one may write:

$$-\frac{dc}{dz} = \left(\frac{C_0}{T_{\max} - T_0} \right) \cdot \frac{dT}{dz} . \qquad (3)$$

Here C_0 is the reagent molar concentration in the initial combustible mixture, T_0 – temperature of initial mixture (indoor temperature), $T_{\max}$ – maximal temperature of the flame zone.

If the solid non-volatile particles of small size and of d_S diameter present the cooling agents of the flame zone, then the velocity of heat flow directed to mentioned particles in the conditions of laminar streamling, may be expressed by following manner :

$$\omega_- = 2\pi\lambda d_S (T - \Theta) N_S , \qquad (4)$$

wherein Θ presents the temperature of solid particle and N_S – the amount of these particles in the unit of gas volume.

For characterization of fire-extinguishing efficiency of powdered additives the so-called “mass concentration” of the powder in the gass (W) is frequently used which reflects the total mass of solid particles in the unit of the volume of reaction mixture. On this basis the expression (4) takes the following form:

$$\omega_- = 2\lambda (T - \Theta) \frac{W \cdot S_S}{d_S} . \qquad (5)$$

Here S_S presents the specific surface of spheric solid particles.

The heat released over time dt in the unit of the volume of the flame zone comprises $\omega_+ dt = \frac{\omega_+}{v_0} dz.$ The total heat released in the volume unit may be expressed as the following integral:

$$I_+ = \frac{1}{v_0} \int_0^l \omega_+ d_z , \qquad (6)$$

where l is the thickness of flame zone. Similarly, the total heat transferred to the solid particles from the volume unit of the flame zone becomes the following:

$$I_- = \frac{1}{v_0} \int_0^l \omega_- d_z . \qquad (7)$$

On this basis the ratio $\frac{I_-}{I_+}$ may be taken as the quantitative measure of the efficiency of cooling action of the solid particles:

$$\alpha = \frac{I_-}{I_+} = \frac{\int_0^i \omega_- d_z}{\int_0^i \omega_+ d_z} . \qquad (8)$$

To evaluate the coefficient α the next model system was chosen: the flame spreads in methane-air stoichiometric mixture (9,6 % CH_4+ 90,4% air) “bottom-up” at atmospheric pressure and initial indoor temperature. The solid particles move by the velocity $3m \cdot s^{-1}$ in the direction counter to the combustion wave (it should be noted that such conditions correspond to our experiments performed earlier). Corresponding data for $NaCl$ were selected as physical characteristics of solid particles.

By the use of expressions (2) – (3) the values of the velocity ω_+ were determined in conditions of various temperatures by means of graphical differentiation.

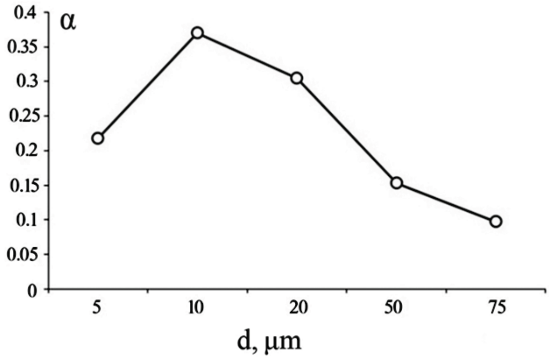

Fig. Variation of α coefficient with diameter of solid particles in the combustion of methane at atmospheric pressure.

Our preliminary experiments have shown that at suppression of methane-air flame propagation in vertical cylindrical tube by the powders of $NaCl$ the product $W \cdot S_S$ nearly comprises $70m^{-1}$ (if the diameter of solid particles is in the range $10\mu m - 100\mu m$). On this basis and by the use of formula (5) the values of velocity ω_- were calculated in the conditions of delivery of solid particles of various size to the methane-air flame. The temperature dependence of λ coefficient for isobaric conditions as well as possible evaporation of particles was taken into account at the calculations.

The numerical integration of the funcions $\omega_+(z)$ and $\omega_-(z)$ was carried out for estimation of the total heat (I_+) released in the volume unit of flame zone and of the total heat (I_-) transfer to the solid particles. For this reason the Simpson' rule was used; the step of integration comprised $\Delta z = 0{,}1mm$. On the basis of the data obtained the values of α coefficient were estimated for the solid particles of various diameter. The results are given in the Fig. It is evident that the numerical values of α are not small. This fact means that the sufficiently large part of heat energy, released in combustion zone, is transferred to the solid particles and isn't consumed for the flame further propagation hindering the combustion process.

In conclusion, we can say the following: in the process of fire extinguishing by the powders, prepared on the basis of inorganic salts, the thermal effects may play a significant role. Besides the chemical inhibition this circumstance must be taken into account in the course of the study of total complex process of the suppression of combustion reaction.

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ალის გავრცელების თერმული ინჰიბირება

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სადღეისოდ ითვლება, რომ არაორგანულ მარილთა ფხვნილების ნაწილაკებით ლამინარული ალის ინჰიბირებისას განსაკუთრებული მნიშვნელობა ენიჭება წვის რეაქციის ქიმიურ ინჰიბირებას. რაც შეეხება ალის გავრცელების თერმულ ინჰიბირებას (წვის ზონის გაცივების ეფექტს) მყარი ნაწილაკების თანაობისას, მისი როლი ალის ჩახშობის ჯამურ პროცესში ბოლომდე გარკვეული არ არის. წარმოდგენილი ნაშრომის მიზანს შეადგენს თეორიულ გაანგარიშებათა საფუძველზე იმის გარკვევა, შეუძლია თუ არა თერმულ ინჰიბირებას აქტიური კონკურენცია გაუწიოს წვის ზონაში სითბოგამოყოფას. მოდელურ პროცესად შერჩეული იყო ალის გავრცელება მეთანი-ჰაერის სტექიომეტრულ ნარევში. მაინჰიბირებელ აგენტებს წარმოადგენს სხვადასხვა დიამეტრის მქონე NaCl-ის მყარი სფერული ნაწილაკები. გამოთვლილ იქნა ალის ზონაში სითბოგამოყოფისა და მყარ ნაწილაკებზე სითბოგადაცემის სიჩქარეები. შესაბამის ინტეგრალურ გამოსახულებათა ამოხსნისათვის გამოყენებული იყო სიმპსონის წესი. მიღებული შედეგების საფუძველზე შეიძლება დავასკვნათ, რომ არაორგანულ მარილთა მყარი ნაწილაკების მიერ ალის გაცივების ეფექტს რეალურად შეუძლია მნიშვნელოვანი წვლილი შეიტანოს წვის რეაქციის ინჰიბირების ჯამურ პროცესში.

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