The Analytical Method of Calculation of the Time Characteristics of the Gaseous Suspension Ignition with a Heated Body

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Abstract.

The dependences of the time characteristics of ignition of a gaseous suspension with a heated body on the gaverning parameters of the process have been determined with the use of the wave ignition theory.

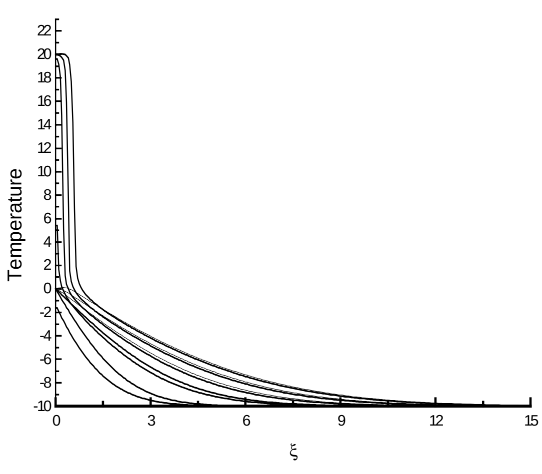
At t = 0, a body heated up to T_{ig} ($T_{ig} > T_0$) is put into a homogeneous gaseous suspension containing N particles per volume unit, the particle and gas temperatures being equal to T_0. The gas heated due to the temperature gradient warms up the particles. The rate of the heterogeneous reaction of the particles with the gas-oxidant increased with the particle temperature initiates the gaseous suspension ignition. It is assumed that at T_0 the reaction rate is equal to zero, the heat exchange between the gas and the particles obeys the Newtonian law and is characterized by the heat exchange coefficient, the heat loss into the walls are negligibly low, the reaction is described by the kinetics of the 1st order, there is no thermic interaction between the particles, the oxidant transport to the particle surface proceeds via the diffusion mechanism.

A two-temperature mathematical model is used for the description of the process at the assumption that the particle and gas temperatures are different.

The criterion analysis of the initial set of equations showed that at the temperature of the heating element T_{ig} there might occur two different ignition modes dependent on the ratio of the specific times of the particle-gas heat exchange t_{ig} and the chemical reaction of oxidation t_{ch}. If the time of heat exchange is much higher than the specific time of oxidation (high ignition temperatures, low values of the $z = t_{ch}/t_{ig}$ parameter), ignition occurs in the diffusion mode, *i.e*. the rate of the particle-gas interaction is determined by the oxidant diffusion to the particle surface and the particle temperature is much higher than that of the heating element (Fig. 1).

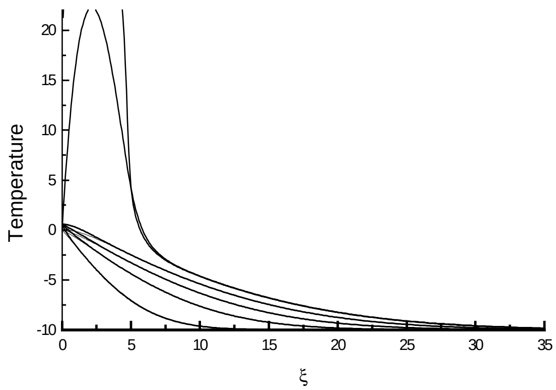
. DIFFUSION-CONTROLLED (TWO-TEMPERATURE) REGIME OF IGNITION

$z<z_{cr}\approx 1$, $(\theta_p-\theta_g)_{\max}\approx 1/\gamma_1$, $\tau_0=14{,}5$



At $t_{ch} > t_{ig}$, the kinetic mode of ignition is observed. The gaseous suspension is ignited at the equal temperature of the gas and the particles, *i.e*. the process can be described by an uni-temperature model (Fig. 2).
Kinetic-controlled (one-temperature) regime of ignition

$$z > z_{cr} \approx 1 \quad (\theta_g \approx \theta_p), \ \tau_0 = 108$$



Analysis of the specific features of ignition in both cases was performed on the base of the wave ignition theory (WIT) [1]. According to WIT, the time characteristics of ignition are presented via the parameters of the intermediate combustion wave (ICW). ICW is a stationary combustion wave with the maximum gas temperature equal to the ignition temperature. This approach allows treatment of the specific features of the gaseous suspension ignition as those of a particular source of heat release.

In the case of one-temeprature ignition regime the following ICW parameters were determined by the narrow zone method by Zeldovich and Frank-Kamenetskii [2]: the heat flow from the reaction zone q_{st}, the reaction zone area ξ_{st}, the heating zone length L_{th}, and the front velocity w.

$$q_{st} = \sqrt{B}\sqrt{2}, \ \xi_{st} = \frac{\sqrt{2}}{\sqrt{B}}, \ L_{th} = \frac{(1+B)\theta_{in}}{\sqrt{B}\sqrt{2}}$$

$$\omega = \frac{\sqrt{B}\sqrt{2}}{(1+B)\theta_{in}}$$

Then the analytical expressions of the dimensionlesstimes of inert heating τ_{in}, the zero gradient establishment τ_0, and the thermal equilibrium break-off τ_{ig} are

$$\tau_{in} = \frac{(1+B)\,\theta_{in}^2}{B\,2\pi}$$

$$\tau_0 = \tau_{in} + \frac{1+B}{B}\theta_{in} = \frac{1+B}{B}\left(\frac{\theta_{in}^{\ 2}}{2\pi} + \theta_{in}\right)$$

$$\tau_{ig} = \tau_0 + \frac{1+B}{B}\theta_{in} = \frac{1+B}{B}\left(\frac{\theta_{in}^{\ 2}}{2\pi} + 2\theta_{in}\right)$$

Calculation of the ICW parameters for the case of the diffusion regime of ignition ($z < z_{cr}$) can be based on the data of [3]::

$$q_{st} = \sqrt{2}\sqrt{\frac{Bz}{\gamma_1}}, \quad \xi_{st} = \frac{\sqrt{2}}{\sqrt{B}}\sqrt{\frac{\gamma_1}{z}}$$

$$\omega = \frac{\sqrt{B}\sqrt{2}}{(1+B)\theta_{in}}\sqrt{\frac{z}{\gamma_1}}$$

here z/γ_1 is the dimensionless rate of the diffusion interaction of the oxidant and the particles.

Hence, the analytical expressions for τ_{in}, τ_0 can be transformed to

$$\tau_{in} = \frac{\gamma_1}{z}\frac{(1+B)\,\theta_{in}^2}{B\,2\pi}$$

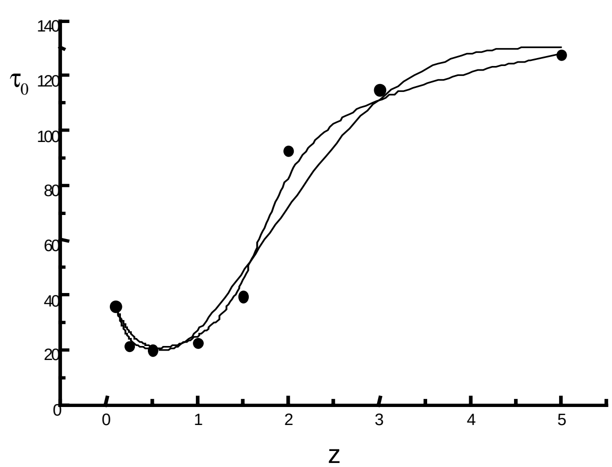
$$\tau_0 = \frac{\gamma_1}{z}\frac{1+B}{B}\left(\frac{\theta_{in}^2}{2\pi} + \theta_{in}\right)$$

The simple expressions obtained take into account the dependence of the ignition time characteristics on the major parameters of the process (the particle mass concentration in the gas, the particle size, the kinetic characteristics of the reaction, the ignition temperature). WIT allowed establishing of the relationship between the critical conditions of an individual particle the modes of the suspension ignition. It was found that the kinetic mode of ignition occurred at the heating agent temperature lower than the critical temperature of ignition of a single particle T_{cr}. while the diffusion mode was observed at the temperatures, which were one specific interval higher than T_{cr}. At $T_{cr} < T_{ig} < T_{cr} + RT_{cr}/E$ (E is the reaction activation energy, R is the universal gas constant), the combustion process proceeds in some intermediate mode, which is characterized by the specific features of both diffusion and kinetic modes.

The reaction rate becomes a few orders higher at the transition from the kinetic to diffusion mode. According to the formulas obtained, the transition is expected to be accompanied by a jump-wise decrease in both the ignition delay time and the energy required for initiation of self-propagating combustion.

Numeric calculation of the initial set of equations confirmed the validity of the main assumptions and conculsions of the approximation analysis. The error of evaluation of the ignition time characteristics did not exceed 40% (Fig. 3).

Dependence of the time of zero gradient formation τ_0 on parameter Z for θ_{in} = - 10.



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