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Determination of the thickness of the flame front using mathematical modeling of the temperature field

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Abstract. The work is devoted to the process of gorenje. Attention was paid to mathematical modeling of the flame temperature field under boundary conditions of the third kind. This takes into account convective heat transfer.

1. Introduction

The increasing consumption of oil and gas every year leads to the need to intensify the processes of its production. The resulting failures of mechanisms, violations of the technological process, as well as natural disasters lead to serious accidents that can be accompanied by large fires, large material losses, deterioration of the environmental situation in the fire zone and adjacent areas, and often-human casualties. Therefore, the study of gorenje processes is not only an independent interest, but also a public one. In this regard, mathematical modeling of gorenje is of interest.

The processes of gorenje fuel are a complex physico-chemical process. These processes are widely used in various branches of modern engineering and technology. Gorenje is a process of oxidation by oxygen of air of hydrocarbons in the gas or vapor phase, which is accompanied by heat release and glow of combustion products. [1]. The chemical reaction proceeds simultaneously with a number of physical processes: mixing of fuel with oxygen, formation of a combustible mixture, heating of this mixture due to the heat released during oxidation, removal of combustion products from the reaction zone.

To describe its properties, simpler models are often used today. Many works have been devoted to the calculation of combustion under various conditions, as well as its parameters [2-9], but the issue of determining the thickness of the flame front has been little studied. The article discusses one of the ways to determine it.

2. Materials and methods

The method of mathematical modeling is used in the work.

3. Results

Flame propagation can be considered as a continuous process of progressive acceleration of the reaction when gas passes through a narrow flame zone under conditions of parallel heat transfer by thermal conductivity and diffusion transfer of gorenje products, including active centers in a fresh mixture and fresh mixture in the combustion zone.

When the flame spreads, the front divides the mass of gas into two parts: in front — a slightly heated gas mixture, behind - strongly heated combustion products. In gorenje, the temperature varies from the initial T_0 to the burning temperature Tc, and between them is a brightly glowing strip - the flame front with a thickness (δ). Since heat is transferred from hot to cold, a heat flow will flow towards the initial mixture, heating the layer adjacent to it, the so-called heating zone. The transfer of heat from it is carried out by thermal conductivity.

Experience shows that with normal flame propagation, chemical reactions take place in a very thin layer separating the unburned part from the combustion products. The thickness of the flame front, even for slow-burning mixtures, is fractions of millimeters. To determine it, we replace the true temperature distribution with a line, drawing a tangent at the inflection point (fig. 1) and continuing it to the intersection with the straight lines T_0 and Tc. The distance between the intersection points δ is the thermal width of the flame front.

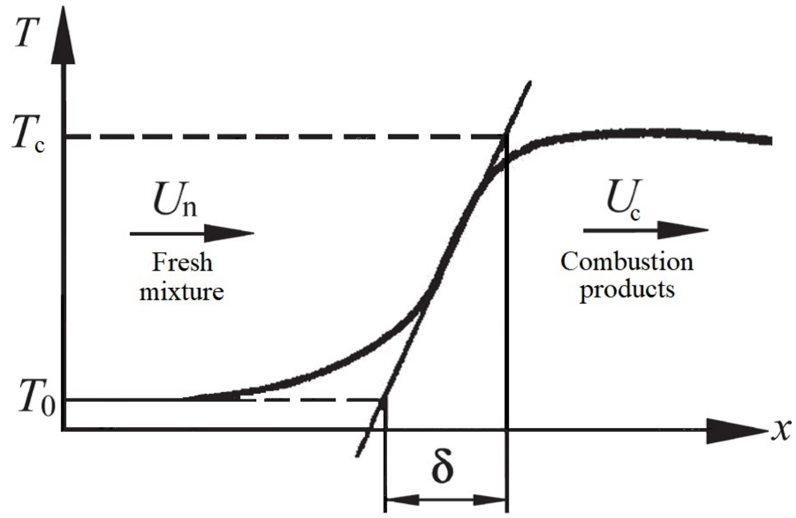

Figure 1. Graphical determination of the thickness of the flame front.

The maximum temperature gradient in the flame can be represented as

$$\left(\frac{dT}{dx}\right)_{\max} = \frac{T_c - T_0}{\delta} \tag{1}$$

The heat flow from the flame zone is used to heat the fresh mixture due to thermal conductivity, therefore

$$q = -\left(\frac{dT}{dx}\right)_{\max} = \frac{T_c - T_0}{\delta} \tag{2}$$

To simplify the simulation, imagine a flame in the form of a ball. The same heat source with a specific power of q_v operates inside. With continuous fuel supply, we will consider the process stationary. To find the distribution of the temperature field, it is necessary to solve the Poisson equation [10]

$$\Delta T + \frac{q_v}{\lambda} = 0 \tag{3}$$

expression (2) in a spherical coordinate system will take the form

$$\frac{1}{r^2}\frac{d}{dr}\left(r^2\frac{dT}{dr}\right)=-\frac{q_v}{\lambda} \tag{4}$$

let's separate the variables

$$\frac{d}{dr}\left(r^2\frac{dT}{dr}\right)=-\frac{q_v}{\lambda}r^2 \tag{5}$$

let 's integrate both parts of the equation

$$r^2\frac{dT}{dr}=-\frac{q_v r^3}{3\lambda}+C_1 \tag{6}$$

let's separate the variables again

$$\frac{dT}{dr}=-\frac{q_v r}{3\lambda}+\frac{C_1}{r^2} \tag{7}$$

re-integrate both parts of the equation

$$T=-\frac{q_v r^2}{6\lambda}-\frac{C_1}{r}+C_2 \tag{8}$$

Constant C_1 =0 due to the final temperature value in the center. Then

$$T=-\frac{q_v r^2}{6\lambda}+C_2 \tag{9}$$

We find the constant C_2 from the boundary condition. Thermal interaction with the medium takes place on the flame surface, which we will describe by a boundary condition of the third kind

$$\lambda\left.\frac{dT}{dr}\right|_{r=R}=-\alpha(T_c-T_0) \tag{10}$$

substituting (9) into (10), we get

$$\frac{q_v R}{3}=\alpha\left(-\frac{q_v R^2}{6\lambda}+C-T_0\right) \tag{11}$$

from where the integration constant C_2 is equal to

$$C_2=T_0+\frac{q_v R}{3\alpha}+\frac{q_v R^2}{6\lambda} \tag{12}$$

then the law of temperature distribution will take the form

$$T=T_0+\frac{q_v R}{3\alpha}+\frac{q_v(R^2-r^2)}{6\lambda} \tag{13}$$

The flame surface temperature is

$$T_c=T_0+\frac{q_v R}{3\alpha} \tag{14}$$

where from

$$T_c - T_0 = \frac{q_v R}{3\alpha} \tag{15}$$

Find the value of the derivative of the temperature (13) on the surface

$$\left.\frac{dT}{dr}\right|_{r=R} = -\frac{q_v R}{3\lambda} \tag{16}$$

from formula (2), the thickness of the flame front is

$$\delta = -\frac{T_c - T_0}{\left(\frac{dT}{dr}\right)_{r=R}} = \frac{\lambda}{\alpha} \tag{17}$$

Let's use the dimensionless Bio number, which is the ratio of the thermal resistance of the wall to the thermal resistance of heat transfer on the surface

$$Bi = \frac{\alpha l}{\lambda} \tag{18}$$

where l is the defining (characteristic) size. It follows from expression (13) that Bi = 1.

4. Discussion

The obtained formula (17) makes it quite easy to find the value of the thickness of the flame front. Only the physical characteristics of the gas are sufficient for this. As follows from it, the thickness value is determined by only two parameters.

In the end, we switched to the number of similarity of Bio and this is not an accident:

- The Bio number is one of the criteria for the similarity of stationary heat exchange. Just the problem was considered stationary.
- The Bio number appears when analyzing the boundary condition of the third kind, which corresponds to the solution.
- A Bio number greater than 0.1 indicates that the temperature field of the flame is inhomogeneous.

5. Conclusion

The work is devoted to modeling the process of gorenje fuel. One of the methods for calculating the thickness of the flame front is proposed. It considers the stationary gorenje process at convective heat exchange without taking into account radiation heat exchange. The obtained result can be useful for further theoretical research in this field.

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