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Investigation of formation of burning harmful emissions at methane

Abstract. The present paper is devoted to the study of the influence of the speed of cocurrent oxidizer flow on the concentration of carbonic gas at methane burning in the flat channel. We working out of new ways of reduction of emissions of harmful substances by means of physical models is on the one hand connected with large expenses on physical experiments, on the other hand, such working out can give only suggestions for the solution of partial problems as it is impossible to carry out physical modeling of all processes proceeding in the combustion chamber and in flues in the installations reduced on scale. This is problem can be solved only on the basis of system analysis, mathematical and imitating modeling. It is a logical result as after burning is completed, carbon dioxide is not formed. With the removal of the entrance channel of CO₂ concentration on the walls ($y / H = 1$) of the channel increases, as they are impenetrable.

Keywords: methane, turbulent, flux, numerical investigation, influence degree

Introduction

An increasing attention paid nowadays to the environmental problems and the crisis of raw materials put forward the problems of the most economical and optimum burning of fuel with minimal emissions of harmful substances. The solution of these problems requires a detailed knowledge of the influence of various factors on the considered processes of fuel combustion.

In this connection research of the processes of burning gaseous, liquid and solid fuel is now extremely actual, and creation of modern methods of burning and reduction of emission of toxic substances to the atmosphere, in particular, for powerful power-generating units, has important economic value.

Working out of new ways of reduction of emissions of harmful substances by means of physical models is on the one hand connected with large expenses on physical experiments, on the other hand, such working out can give only suggestions for the solution of partial problems as it is impossible to carry out physical modeling of all processes proceeding in the combustion chamber and in flues in the installations reduced on scale. This is problem can be solved only on the basis of system analysis, mathematical and imitating modeling.

Thus, the energy crisis and problems of ecology demand efficient control processes of fuel burning with necessary influence on various

parameters by means of the computer and forecasting of the result of such influence which has been long used in developed countries.

Therefore the computing experiment was become one of economically effective and convenient means of a detailed analysis and deeper understanding of difficult physical phenomena. A strict mathematical description of the process at accompanying fuel burning in combination as with modern computing algorithms in combination with super-computers allow to solve these problems for concrete installations.

In the present paper the problem of diffusive burning of a turbulent methane flux is considered. The turbulent methane flux flows from a flat crack of height h with initial speed u_{01} , reference temperature T_{01} and initial concentration of fuel c_{01} . The cocurrent stream of an oxidizer has initial parameters u_{02} , T_{02} , c_{02} . In the area of where the methane flux mixes with oxidizer flux a burning front is formed creating a diffusive torch. The problem of the scheme is presented on Fig. 1.

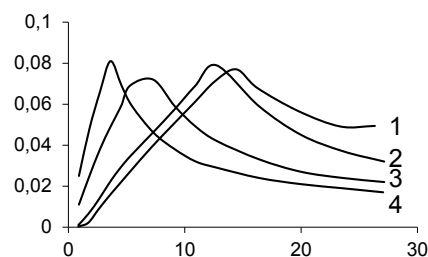
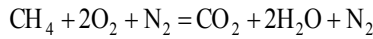


Figure 1 – Scheme of a current

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The reaction of methane burning [1]:



Here, methane (CH₄) is a fuel, oxygen (O₂) is an oxidizer, carbonic gas (CO₂) and water (H₂O) are reaction products, nitrogen (N₂) acts as an inert dilutant.

The continuity equation:

$$\frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} = 0 \tag{2}$$

The equation of motion:

$$\rho u \frac{\partial u}{\partial x} + \rho v \frac{\partial u}{\partial y} = -\frac{\partial p}{\partial x} + \frac{\partial}{\partial y} \left(\mu_{\text{эф}} \frac{\partial u}{\partial y} \right) \tag{3}$$

The equation of transfer of methane concentration:

$$\rho u \frac{\partial c_1}{\partial x} + \rho v \frac{\partial c_1}{\partial y} = \frac{\partial}{\partial y} \left(\frac{\mu_{\text{эф}}}{\text{Sc}_{\text{эф}}} \frac{\partial c_1}{\partial y} \right) - \sigma k_0 \rho^2 c_1 c_2 \exp\left(-\frac{E}{RT}\right)$$

The equations of transfer of Burke-Shumans variables:

$$\rho u \frac{\partial \tilde{c}_i}{\partial x} + \rho v \frac{\partial \tilde{c}_i}{\partial y} = \frac{\partial}{\partial y} \left(\frac{\mu_{\text{эф}}}{\text{Sc}_{\text{эф}}} \frac{\partial \tilde{c}_i}{\partial y} \right), \tilde{c}_i = c_i + \sigma_i c_1, \tag{4}$$

$i = 2, 3, 4.$

The energy equation:

$$\rho u \frac{\partial H}{\partial x} + \rho v \frac{\partial H}{\partial y} = \frac{\partial}{\partial y} \left(\frac{\mu_{\text{эф}}}{\text{Pr}_{\text{эф}}} \frac{\partial H}{\partial y} \right), H = c_p T + Qc_1$$

Here C₁ is the concentration of methane, C₂ is the concentration of oxygen, C₃ is the concentration of carbonic gas, C₄ is a concentration of water vapor, C₅ is the concentration of nitrogen.

Boundary conditions

The boundary conditions for the equations (3)-(7), (10)-(12) are set as follows:

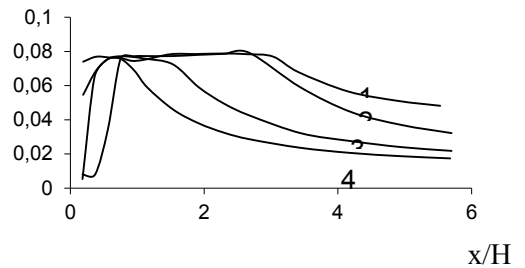
$x=0:$
 $0 < y < h:$
 $u = u_{01}; \quad c_1 = c_{01}, \quad H_0 = c_p T_0 + Qc_{10}$
 $h < y < H:$
 $u = u_{02}; \quad c_1 = 0; \quad H_0 = c_p T_0$

$0 < y < H:$ $k_0 = \alpha_1 u_0^2,$
 $\varepsilon_0 = \alpha_2 \frac{k_0^{3/2}}{L_0};$
 $\overline{T_0'^2} = \alpha_3 (T_w - T_0)^2$
 $x^3 \rightarrow 0, y=0$
 $\frac{\partial u}{\partial y} = \frac{\partial H}{\partial y} = \frac{\partial c_{fu}}{\partial y} = \frac{\partial \tilde{c}}{\partial y} = \frac{\partial k}{\partial y} = \frac{\partial \varepsilon}{\partial y} = \frac{\partial \overline{T'^2}}{\partial y} = 0$
 $x^3 \rightarrow 0, \quad y=H: \quad u = v = k = 0,$
 $T = T_w = \text{const},$
 $\frac{\partial H}{\partial y} = \frac{\partial c_{fu}}{\partial y} = \frac{\partial \tilde{c}}{\partial y} = \frac{\partial \varepsilon}{\partial y} = \frac{\partial \overline{T'^2}}{\partial y} = 0$

Problem Solution

For numerical integration of the problem Patankar-Spoldings method was used. The numerical solution was obtained for $u_{ox_0} = 0,5 \text{ m/s}, 1 \text{ m/s}, 1,5 \text{ m/s}, 2 \text{ m/s}.$ The results of calculations are presented in Figure 2-6.

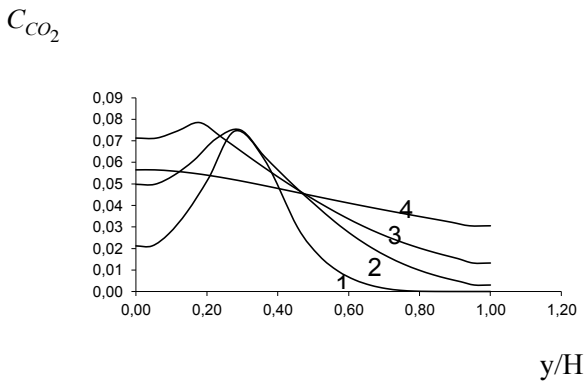
$$C_{CO_2} \tag{4}$$



$$m: 1 - 0,25; 2 - 0,50; 3 - 0,75; 4 - 1 \tag{6}$$

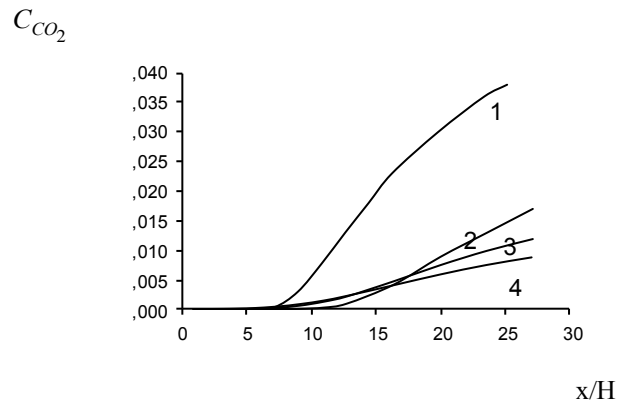
Figure 2 – The influence of cocurrent flows on the concentration of carbon dioxide in the flame front

In figure 2 influence of speed cocurrent a stream on change-nie of the maximum concentration of carbonic gas along the channel is shown. From drawing it is visible that the maximum quantity of carbonic gas formed at burning of methane from speed cocurrent stream doesn't depend. As shown in [14], with increase in speed cocurrent stream at $m=0, 5$ the length of a torch decreases. In a kernel of a torch concentration CO₂ remains to a constant until burning won't end, and after that maintenance CO₂ decreases for channel axes at the expense of diffusion in the priest-river a direction [2].



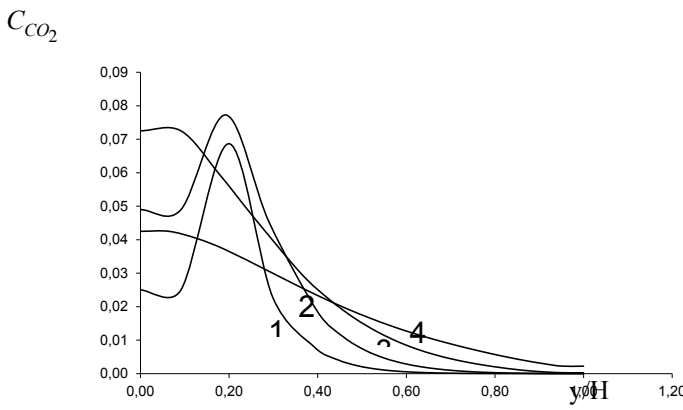
x: 1 – 0,92; 2 – 1,88; 3 – 2,65; 4 – 4,16

Figure 3 – Distribution of carbon dioxide various cross-section sections of the channel at m=0, 25



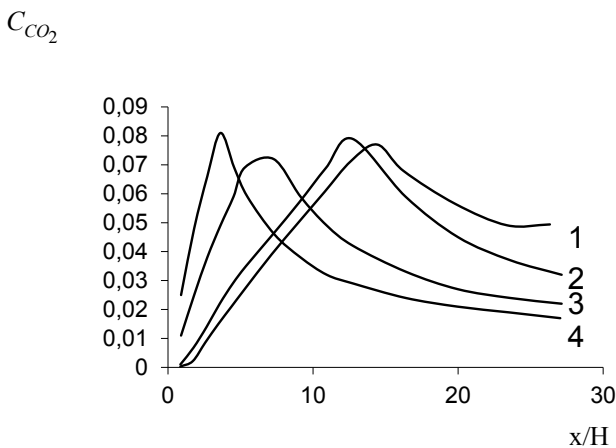
m: 1 – 0,25; 2 – 0,50; 3 – 0,75; 4 – 1

Figure 6 – Change of concentration of the carbon dioxide on channel walls at various parameters of cocurrent flow



x: 1 – 0,38; 2 – 0,76; 3 – 1,53; 4 – 2,68

Figure 4 – Distribution of carbon dioxide various cross-section sections of the channel at m=0, 75



m: 1 – 0,25; 2 – 0,50; 3 – 0,75; 4 – 1

Figure 5 – Change of concentration of carbon dioxide on a channel axis at various parameters of cocurrent flow

In figure 3 and 4 distribution of concentration of carbon dioxide across the channel in various sections is shown at m=0, 25 (drawing 3) and m=75 (drawing 4) First three sections are taken in a torch kernel, and the fourth – in that area where burning has ended. From these figures it is visible that concentration has the maximum values in flame front.

On the axis of the channel ($y / H = 0$) the concentration of CO₂ in the core increases to the torch until the combustion is not complete, and then decreases. This can be seen in Figure 5. Such a pattern is observed for all parameters cocurrent flow. It is a logical result as after burning is completed, carbon dioxide is not formed. With the removal of the entrance channel of CO₂ concentration on the walls ($y / H = 1$) of the channel increases, as they are impenetrable. Figure 6 shows that the CO₂ concentration at the wall is higher, the lower the rate of cocurrent flow. Apparently this is due to the fact that the cocurrent flow near the wall prevents the penetration of carbon dioxide to the walls of the channel and communicates them [3].

Conclusion

In this paper is numerically investigated the effect of cocurrent flow rate of oxidant concentration of carbon dioxide during combustion of methane in a flat channel. The following conclusions are drawn based on the analysis of the solution:

1. At increasing of speed cocurrent flow the length of a torch decreases, and the maximum concentration of carbon dioxide doesn't depend from speed of cocurrent flow.
2. In a torch kernel the maximum concentration of carbon dioxide is observed in a flame front, and this value remains to constants until burning won't end.
3. On an axis of the channel concentration of carbon dioxide grows and reaches the maximum value in the end of a torch at all parameters of cocurrent flow.

4. On internal walls of the channel concentration of carbon dioxide grows more strongly, than it is less speed of cocurrent flow.

In the future it is supposed to take into account the mathematical model of the formation of other harmful products of the reaction of carbon monoxide (CO), soot (C) and nitrogen oxides (NO_x).

References:

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