

## NUMERICAL MODELING OF THE COMBUSTION OF PRE-MIXED FUEL IN MICROMODULE BURNER

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**Abstract.** The article presents the results of numerical simulation for the combustion of pre-mixed fuel in micromodule. The study prerequisites, burner model and the initial modeling conditions are presented.

It is shown that the burner has high environmental performance outside the stoichiometry zone. The dependences of temperatures on the coefficient of excess fuel are presented, which confirm the dependence of the concentration of nitrogen oxides on the excess fuel.

The concluding section presents a formula for calculating the concentration of nitrogen oxides based on the temperature in the combustion zone.

### 1. Introduction

Combustion chambers with preliminary fuel mixing are the most effective in terms of reducing the formation of toxic substances. With a rather lean mixture and high mixing efficiency, the formation of toxic substances, in particular nitrogen oxides, has a low intensity [1]. This circumstance is explained by the lack of zones with a high concentration of fuel and a decrease in the average temperature in the combustion zone.

The best option for homogenization is pre-mixing the air-fuel mixture before the intake into the combustion chamber. As a result, the time needed for mixture is excluded from the time spent in the high temperature zone, which reduces the emission of nitrogen oxides, reduces the size of the combustion zone and accordingly, reduces the size of the combustion chamber. According to numerous studies [1-6], the emission of nitrogen oxides can be reduced by 25-30%, depending on the design and operating parameters of the burner. In some cases, a positive effect was obtained by turbulization of the flow using turbulators.

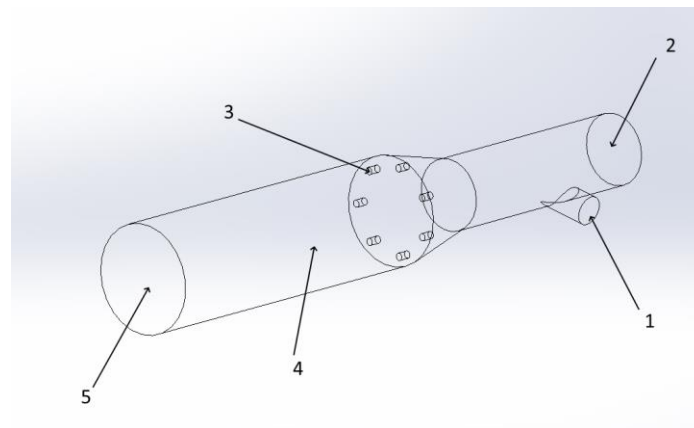
In a homogeneous combustion chambers, the air-fuel mixture is fed into the combustion zone with a fuel excess  $\varphi = 0.5-0.6$ . Moreover, primary air is supplied in a ratio of 30/70, primary and secondary, respectively. A high effect can be achieved using micromodular combustion chambers, a feature

where the torch is divided into smaller ones due to the individual preparation of the fuel-air mixture in an atomizer called micromodule.

The article presents the results of the study of a micromodular burner with a tangential supply of fuel.

## 2. General data on the modeling process

Figure 1 shows a general view of the burner. It consists of the following elements: 1 - fuel nozzle, 2 - air supply, 3 - nozzles for secondary air supply, 4 - combustion zone, 5 - exit zone. The basic principle of the burner is the supply of partially mixed air to the combustion zone. The secondary air is supplied through 7 nozzles located radially around the axis. The diameter of the nozzles is 3 mm, the diameter of the main zone is 70 mm, the diameter of the inlet air section is 30 mm, and the diameter is 12 mm.



1 - fuel nozzle, 2 - air supply, 3 - nozzles for secondary air supply, 4 - combustion zone, 5 - exit zone

Figure 1 - General view of the micromodule burnerA subsection

## 3. Physical Model and mesh

For the simulation, the k-ε realizable turbulent model was used, which has high accuracy. Previous studies have proven the relevance of the used model [7]. Thermal conductivity, density, viscosity and air density were constant. The heat capacity of the gases changed according to the piecewise linear function, and the density by the PDF function. In the simulation, the combustion function of a partially mixed air-fuel mixture was used. Fuel was mixed into the primary air, and secondary air was supplied directly to the combustion zone.

The initial conditions are presented in table 1. The fuel consumption was constant, the equivalence ratio changed by changing the flow rate of primary and secondary air. The equivalence ratio was calculated by the formula:

$$\varphi = \frac{A_0/F_0}{A/F}$$

where  $A_0/F_0$  is the stoichiometric air fuel ratio,  $A/F$  is the actual air fuel ratio.

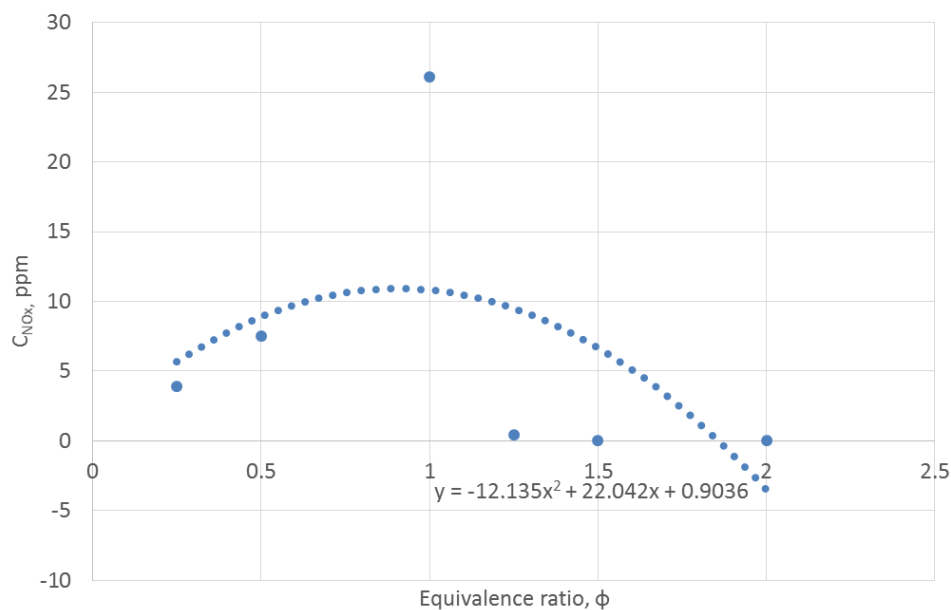
**Table 1.** Initial modeling conditions

№	$\phi$	Air temperature, K	Fuel flowrate, kg/s	Primary air flowrate, kg/s	Secondary air flowrate, kg/s
1	2			0.0014	0.0033
2	1,5			0.0019	0.0044
3	1,25			0.0023	0.0053
4	1	400	0,001	0.0029	0.0067
5	0,5			0.0057	0.0133
6	0,25			0.0114	0.0267

## 4. Results

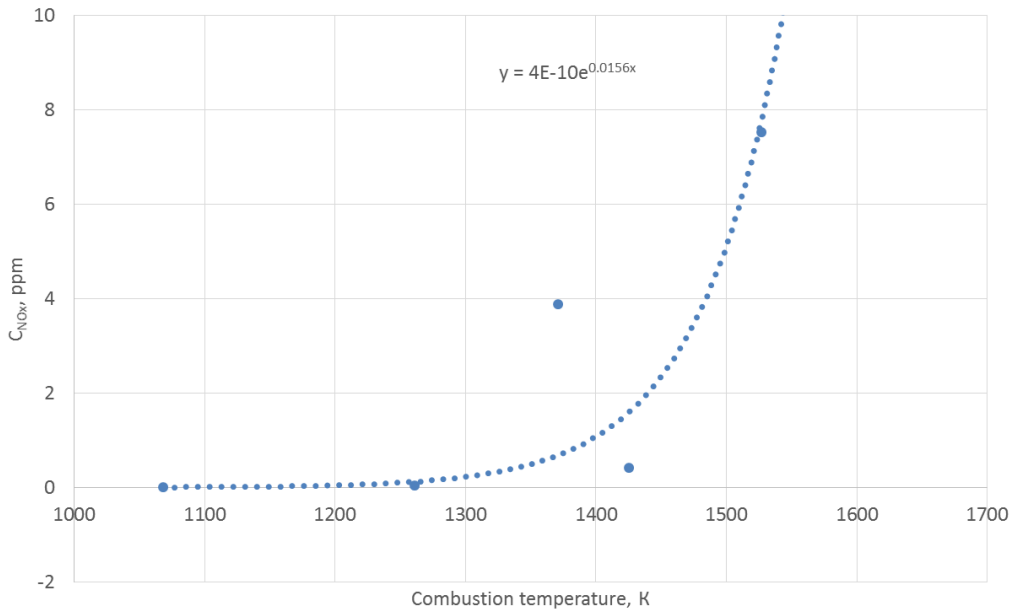
### 4.1. NOx emissions

Figure 2 shows the dependence of the concentration of nitrogen oxides from the equivalence ratio. As it can be seen from the figure, the maximum concentration falls on the stoichiometric ratio of fuel/air. This is confirmed by numerous studies [1,8]. Reducing the formation of nitrogen oxides can be increased by reducing the equivalence ratio, i.e. increased air flow, however, this often leads to increased soot formation. A decrease in the equivalence ratio can lead to a decrease in temperature in the combustion zone and insufficient heat intensity, or even to a blowoff.



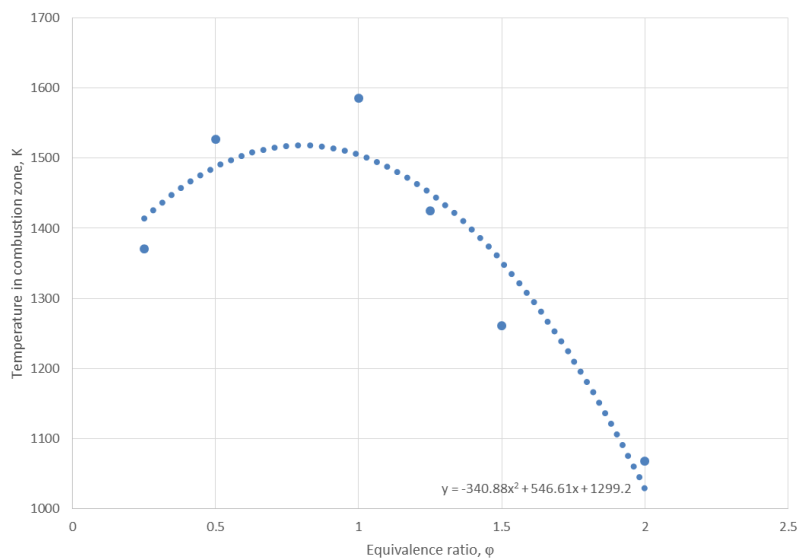
**Figure 2.** Dependence of the concentration of nitrogen oxides from equivalence ratio

Figure 3 shows the dependence of the concentration of nitrogen oxides on the temperature in the combustion zone. As can be seen from the figure, the concentration of nitrogen oxides exponentially depends on the temperature in the combustion zone. It should be noted that temperatures are not presented with reference to the modes ( $\phi$ ). The maximum concentrations correspond to a temperature of 1500 K and the regime  $\phi = 1$ .



**Figure 3.** Dependence of the concentration of nitrogen oxides on temperature in the combustion zone

Figure 4 shows the dependence of the temperature in the combustion zone from the equivalence ratio. As can be seen from the figure, the maximum temperature corresponds to the stoichiometric ratio of fuel/air. An increase in excess fuel leads to a decrease in temperature, and leaving the “poor” part from stoichiometry leads to a more severe drop in temperature than leaving the “rich” one. This is due to the fact that a decrease in air leads to a lack of oxidizing agent for fuel, which leads to an increase in underburning. Increased air consumption leads to complete combustion of the fuel, but the temperature decreases due to the "cooling" of the gases with a large amount of air.

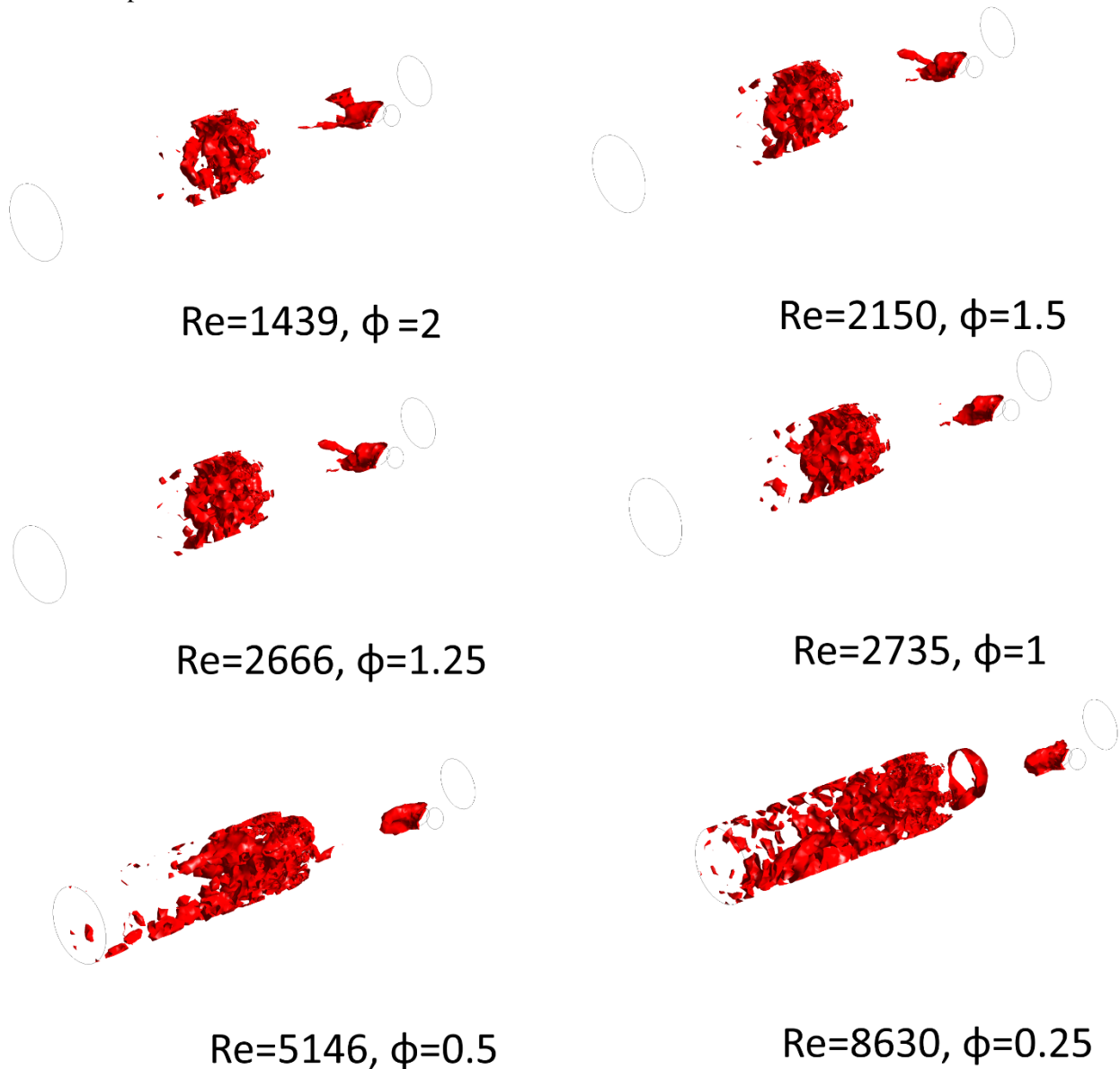


**Figure 4.** The dependence of the temperature in the combustion zone from the equivalence ratio

#### 4.2 Swirling current (vortex formation).

Figure 5 shows the contours of the vortices as a function of the Reynolds number and the equivalence ratio. At low Reynolds numbers, it can be seen that the reverse flow zone is weak, which leads to a small mixing of fuel with air. With increasing air flow, it is seen that the turbulence of the flow increases. However, it can be noted that at the maximum Reynolds number, the transition from one cylindrical part to other leads to an increase in hydraulic losses.

It can be noted that the structure of the vortices is not uniform due to the uneven flow of fuel due to the tangential feed. At high Reynolds numbers, a central zone with a discharge is formed, in which the combustion products and fresh air-fuel mixture are mixed.



**Figure 5.** Vortex formation contours depending on the Reynolds number and equivalence ratio

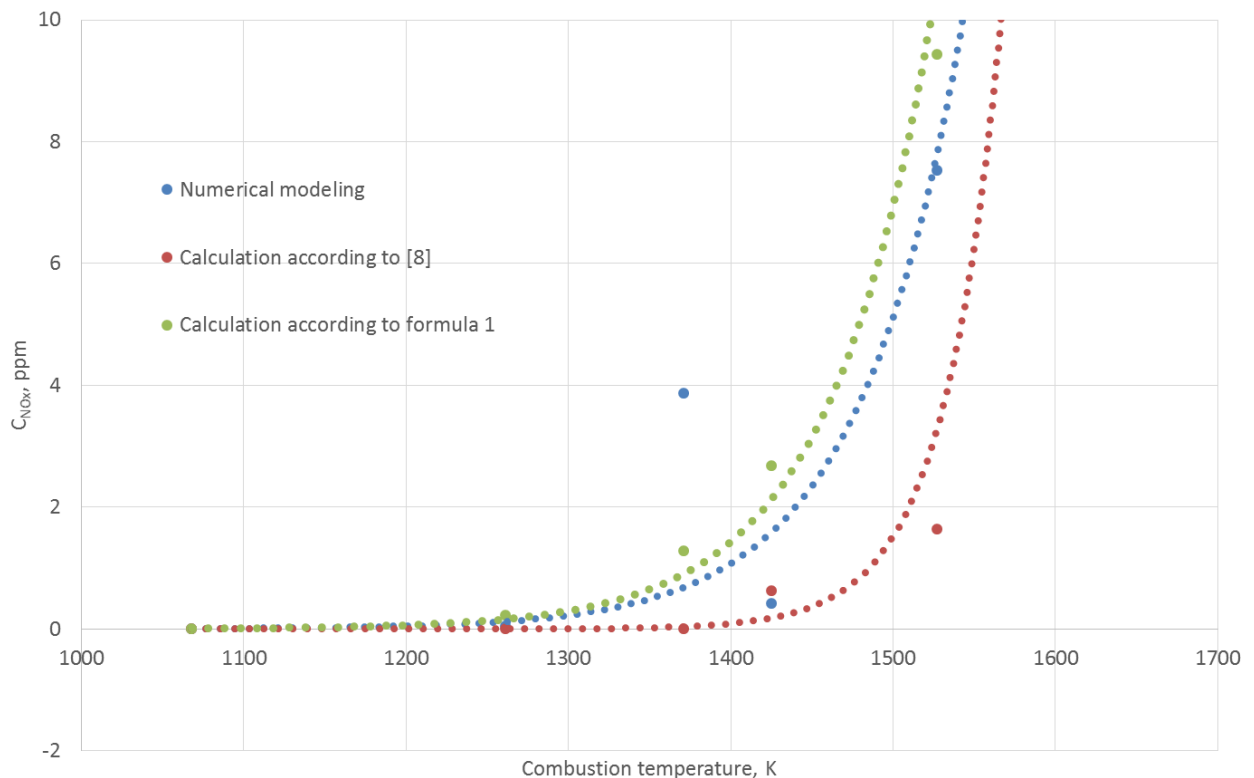
#### 5. The equation for the formation of nitrogen oxides

Based on the results of the analysis, a formula was derived for determining the concentration of nitrogen oxides depending on the temperature in the combustion zone. The formula did not take into account the pressure and residence time of gases in the combustion zone:

$$C_{NOx} = 4 \cdot 10^8 \cdot e^{-\frac{27000}{T_g}} \quad (1)$$

A similar formula is given in [8], the only difference is that this formula takes into account the pressure in the combustion zone and the residence time of the gases.

The calculation results are shown in Figure 6, the graph shows the calculations according to formula 1, according to the formula presented in [8] and the simulation results. The above formula has a fairly high convergence in the entire range. The average difference is 58%.



**Figure 6.** Calculation of the concentration of nitrogen oxides depending on the temperature of the flame by various equations and methods

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